Old Dog, New Tricks

The effect of dynamic road implementation on elder accessibility

Utrecht University

TNO

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Preface

When I was in my teen years my grandmother lived with us in my family home. I still remember trying to help her use a new tablet that she had received as a gift. I thought it would be simple enough to show her how to watch her television programs or read a book; things that would make her life a bit more convenient. However, no matter what strategies I tried to help her learn, there was a block which she could not get past to use this seemingly simple technology. Instead, she continued with the old ways of utilizing the library for books or waiting for the precise moment her television programs came on. She was bound by the technology of her younger days, and in this way was limited to a lifestyle which was becoming increasingly obsolete. I also watched her fall into a state of isolation as her physical mobility declined and she was no longer to operate a vehicle herself or walk any sort of distance. As in many American cities, my hometown is car-centric and therefor has extremely limited mobility options for those either unwilling or unable to drive.

As smart city technologies are being used more in innovative city and mobility design, I often think of my grandmother. I wonder if these new technologies would have helped her have a fuller experience at the end of her life, or if, like trying to learn how to use the tablet, the technology itself is not accessible enough to make opportunities in the urban environment available to elderly populations. Through this study I will evaluate the equity implications of dynamic roads on the less technologically capable elderly population.

Although it is an independent study, my work will contribute to that of the XCARCITY project facilitated through TNO.XCARCITY is focused on finding the right combination of mobility services based on an understanding of user behavior and needs, resulting in adequate levels of sustainable accessibility that achieves desired wellbeing. My focus on elder capabilities will aid in their goal of creating “a list of sustainability, livability, and accessibility KPIs to be considered aimed at structuring the framework of dynamic road space usage” (XCARCITY, 2022, p. 25). Essentially, I am gathering a list of factors that affect the accessibility of elderly populations. XCARCITY aims to reduce space taken by cars and reallocate it to pedestrians and cyclists utilizing dynamic roads. I will evaluate the equity implications of dynamic roads on the less technologically capable elderly population.

I would like to thank my supervisor, Abigail Friendly, for lending her expertise and guiding me through the thesis development process. I would also like to thank my internship supervisor, Carla Robb, for connecting me with many of the brilliant minds at TNO, as well as taking a genuine interest in this project. I want to extend my gratitude to my classmates and colleagues who aided in reviewing, inspiration, Dutch translations, and general maintenance of good sprits during this endeavor. Of course, I will also thank my family and friends back in the United States for supporting me from afar. Finally, I would like to thank all who participated in my survey. Without their valuable input, I would not have been able to complete this project.

Key Information

Abstract

Dynamic road space allocation is a growing topic in the transportation planning sector as more cities contend with lack of space, increased population, and demand for more sustainable designs. The aim for most cities considering these new designs is a move away from the car, in a more gradual way than simply eliminating all familiar four-wheel infrastructure in a single pass. For many people, cars represent freedom of movement in a way that other modes struggle to compete with. A shift away from these modes has the potential to level the playing field when it comes to access to opportunities, but for vulnerable populations like the elderly who are dependent on modes that they have used all their lives, it could pose a threat to access to opportunities and subsequent wellbeing. It is possible to envision a future where a car is not the key to unlocking opportunities in the urban environment, but this vision must be paired with a lens of justice that accounts for many different needs and capabilities. This thesis aims to determine the equity implications of implementing dynamic roads, focusing on elder accessibility. Utilizing Amartya Sen's capabilities approach, I delve into the ways in which elderly populations currently travel and access (social) opportunities and how these travel behaviors might be affected by the implementation of dynamic roads. I use the capabilities approach to conduct a survey in the elderly-dense neighborhood of Buitenveldert which closely neighbors a site of potential dynamic road implementation (near the Amsterdam Zuid station). From the results of the survey, I determine the technological and modal capabilities of this population. Based on this, it was determined that the capabilities required to use dynamic roads do not align with those of the population. Therefore, implementation of a dynamic roads scheme in the area would not align with the equity and accessibility goals of the city of Amsterdam. Issues of route predictability and reliance on the ability to use a smart device prevent this from being an equitable solution to the issue of space optimization. This study concludes with recommendations to create a more equitable strategy for dynamic road implementation.

Key Concepts

Transport justice, dynamic road space allocation, elderly, capabilities

Contents

Introduction

1.1 Why Change our Roads?

The United Nations Human Settlements Programme (UN-Habitat) has laid out goals surrounding the improvement and expansion of public spaces in urban environments, citing environmental, social, health, and wellbeing improvements as the motivation behind prioritizing such spaces (UN-Habitat, 2021). However, finding the room for such spaces in our increasingly crowded cities is a struggle and requires creative thinking and changes to the standard design of urban spaces. Many planners are looking to cut space from the transportation network, shifting away from space-hungry car infrastructure, and veering instead towards the more efficient modes such as transit, walking, and cycling. However, it is still the case that the majority of urban space is in the domain of the car and changing this status quo is a challenge that cities are just starting to grapple with (Petzer et al., 2021).

For generations, cities have kept up the illusion of infinite space, thinking there is always room for more people, places, and things. But in recent years, the problem of overcrowded cities has become more apparent. In a city like Amsterdam, which is already highly dense without much space to expand, continued growth can cause a major problem. The city is projected to have a population increase of about 23% between 2016 and 2040 (OECD, 2017) and as a result there is a need for new strategies for conserving and creating space both for housing as well as the public spaces that make a city more livable. A lack of space is not the only problem associated with an increase in population. Growing numbers of people also put strain on city infrastructure such as transportation systems, contributing to road congestion and making it harder for everyone to move freely in the city. City planners estimate that there is still enough space in cities, but a transformation of underutilized space is needed to meet demand (OECD, 2017). A solution that has started to take shape to solve these problems comes in the form of dynamic road space allocation.

Dynamic road space allocation is a new kind of thinking about our streets, only appearing in the literature in the last ten years. This idea shifts away from the static road design that we have used for generations, and instead focuses on providing street space in proportion to the demand expressed at different times of day. In this way, road space can be transformed to meet growing demand for other uses, better using space that is underutilized. Most roads are only at full use during peak travel hours, but for much of the remaining time of the day, they are mostly empty, representing wasted space. Dynamic roads can be a way to better optimize the road space. For example, at varying times of day, a road might be predominantly used by cars during peak hours or might be converted into a public square during off-peak hours (Valença et al., 2021). One of the first ways we have seen this used is with bus lanes. When road congestion is high, buses can request their lane and make their way easily through an otherwise congested area (Othman et al., 2023). In this way, dynamic roads have the potential to create more public space and reduce congestion while using space that already exists within the city, without expanding.

Access to mobility is important for everyone, but especially for more vulnerable groups such as the elderly, which this thesis will focus on. Transportation networks should grant access to all the basic amenities including food, work, recreation, and social activities. When they don't, the wellbeing of the community suffers. Ensuring transportation accessibility is imperative for maintaining wellbeing, and the needs of elderly road users should be accommodated. By planning for the elderly users of today, we ensure accessibility for the elderly users of tomorrow, which include us.

Background

The following sections define concepts that are vital for the understanding of this thesis. The chapter starts with a review of the importance of access to transportation and issues of aging and accessibility, to grasp the problem at hand. Then the chapter finishes up with sections on how the Dutch government regulates accessibility, then on to definitions of smart cities and dynamic roads.

2.1 Access to Transportation

Transportation is fundamental to maintaining quality of life within an urban environment. By default, it facilitates access to urban amenities and economic and social opportunities simply by providing the tool for humans to move from place to place. A lack of accessible transportation "limits individuals' ability to participate in community life and ultimately results in lower rates of life satisfaction" (Steinfeld & Maisel, 2012, p. 334). It is imperative that transportation options be equally available to all. While this fact may seem obvious to some, many communities lack access to safe and convenient transportation modes that can get them to destinations such as work, school, food, or leisure (Wang et al., 2021). Transportation solutions are not a one-size-fits-all product (Stamatiadis & Hartman, 2011). They must be tailored to the needs and contexts of the communities they are situated in.

The way most cities are currently designed grants cars the right to appropriate a disproportionate amount of road space, creating unsafe streets, which "has curtailed the right to travel to the majority of the population living in cities" (Hérick de Sá et al., 2019, p. 62) and especially for vulnerable populations. The ability to move in a city is what makes all other opportunities possible for residents and is essential for ensuring personal liberty (Dombroski, 2005). Therefore, it is the responsibility of governments and the policies they create to remedy social disparities regarding transportation access by providing suitable options according to differing needs (Mora et al., 2021). Where transit options do exist, the commute to work is what dictates schedules and routes, excluding the desired destinations of older adults and those with special needs (Steinfeld & Maisel, 2012).

Cars are the biggest contributor to traffic deaths (World Health Organization, 2023). More and more, cities are coming to terms with the fact that the most effective way to solve this problem of equality is to change course away from the car. Although the Netherlands is widely regarded as an active mobility haven, a third of Dutch residents still feel that access to a car is a necessity for the fulfilment of their daily needs (Ministry of Infrastructure and Water Management, 2022). There is a balancing act of shifting road infrastructures towards transit and active mobility, while ensuring equality of access for the surrounding community. Transit and active mobility must match, if not outperform, the car when it comes to allowing all people to move efficiently and safely though the city (Semenescu & Coca, 2022). It is imperative that the considerations of marginalized communities such as the elderly sit in the forefront of policymakers' and road designers' minds while they make road-altering decisions.

Hodgson (2012) underlines the idea that understanding the competencies of a population can help improve the overall efficacy of mobility infrastructure. He argues that when it comes to infrastructure designs, and you design for the populations that have the lowest capability thresholds, most of the time it will suit the accessibility needs of the entire population (Hodgson, 2012). Designing for the lowest capability thresholds requires prioritizing bike, walking, and transit; doing so also helps to intertwine different urban activities (improving accessibility) and soothes social inequalities (Power, 2012). However, as Lucas et al. (2016) points out, planners must be careful not to fall into the trap of "offering blanket

concessionary fares to certain targeted population groups, such as older and disabled people… without assessing their actual transport needs" (p. 362). As she notes, mobility is extremely individualized and cannot be generalized even on a household scale as every person has their own specific set of transport capabilities (Lucas et al., 2016). Therefore, when planners allocate one-size-fits-all applications to a community, there are still many who are left without support.

Having case-specific infrastructures poses a significant challenge. In the current system we have in transportation planning, blanket accessibility measures seem to be the best we can do. Lucas (2012) proposes that "a move away from the traditional systems-based approach to transport provision, towards a more people-focused and needs-based social policy perspective" (p. 106) could aid in providing transport solutions that serve mobility needs at an individual scale. This new approach would consider equity of opportunity in regard to accessing desired outcomes, rather than equality of services provided. However, it would require planners to gain an in-depth understanding of the ever-shifting capabilities of the population, so a longer and more citizen-inclusive approach to design would be needed. By including citizens in the process, planners can gain valuable insights for the needs of specific groups, like the elderly.

2.2 Aging and Access

Life expectancy in the world is ever increasing, and as a result the proportion of the population that is over the age of 65 (elderly) is also increasing. As people age, their functional mobility (the ability to autonomously move our bodies) declines. They develop slower reaction speed, balance impairment, lower levels of eyesight, among other things that limit their ability to travel in the way that they are used to (Gemeente Amsterdam, 2016). This has detrimental effects on the ability for elders to get from point A to point B in their daily lives, limiting social interaction, recreational opportunity, and access to businesses and services (World Health Organization, 2007). Essentially, as people age, their ability to live full lives becomes more tied to the level of services in their immediate vicinity. Utilizing transit becomes a key to unlock increased quality of life. Elder wellbeing can be a good indicator of transit system quality due to this fact. Elderly people generally have a lower level of wellbeing than their younger counterparts due to less options in mobility. For example, in Amsterdam, residents over the age of 55 have lower than average levels of wellbeing (City of Amsterdam, 2022). This indicates that there is room for growth in the transportation system in parts of Amsterdam in order to better connect elderly residents to the amenities that would improve their overall wellbeing.

The World Health Organization (2007) has created a guide for evaluating the age-friendliness of a city and this guide specifically highlights the importance of transit access. Access requires that transit be reliable, and notes that changing routes and conditions of travel are not conducive to an age-friendly environment (World Health Organization, 2007). It also requires that clear information about travel conditions and routes be easily accessible to a variety of cognitive levels. This includes having clear signage and notifications of changes to users. Having reliable and up-to-date information available poses a great challenge at the intersection of dynamic roads and elderly access, as the way information is shared about these (potentially) unpredictable road uses is via smart devices. Use of smart devices and other new technology can pose a challenge to elderly people, as this thesis explores.

2.3 Aging and Technology

Technology has the potential to help older adults access information, but only if they know how to use it. Learning new technologies is often a challenge for the elderly, as they experience higher levels of

frustration with learning new things, and have low technological literacy (Harris et al., 2022). However, this does not mean they are incapable of learning some technology skills.

Finkelstein et al., 2023 find that with the right support, older adults are able to learn, to a limited extent, a few functions that can improve their daily lives. They go on to say, however, that there is no one-size-fits-all solution for teaching the elderly to use technology. Learning must be done in accordance with each individual's capabilities and preferences, and there are some tasks that are more difficult than others. (Finkelstein et al., 2023). For example, their study found that elderly users found interacting with a service provider via zoom or online classes the easiest, while other tasks were more difficult. From this statistic, they were able to determine that "many people mastered what they were explicitly taught but are less inclined to venture further into the options/opportunities their devices provide or transfer the learned skills to perform other activities" (Finkelstein et al., 2023, p. 7). While older adults are not incapable of learning new technologies, certain accommodations must be made in order to engage them in technological advancement and maintain their levels of access in the city (Kopeć et al., 2017). However, even though the ability to learn is not off the table for this group, some may prefer to remain offline. Even so, access to social interaction, information, and other opportunities must remain available for anyone with a technological barrier (Finkelstein et al., 2023).

2.4 Aging and Cars

The fact that the elderly find it difficult to use technology pushes them back towards traditional forms transportation, like the car. A common perception is that driving a car is the most comfortable and convenient way to move around. Even in one of the most bikeable, and transit-friendly countries in the world, car ownership in the Netherlands is on the rise (Centraal Bureau voor Statistiek, 2022). In the elderly community especially, the car remains increasingly popular with this group. Car ownership levels rose from 325 cars per 1000 people aged 75 and older in 2008, to 437 cars per 1000 people aged 75 and older in 2018 (Centraal Bureau voor Statistiek, 2022). However, this statistic does not reflect the fact that as we get older, our ability to drive safely in an urban environment quickly, oftentimes suddenly, deteriorates (Cui et al., 2017). In the Netherlands, when drivers reach the age of 75, they must submit a *Declaration of Fitness to Drive* in order to keep their driver's license. To maintain their driver's license, they must be assessed by a doctor who determines if they still maintain the correct facilities to operate a vehicle, if not, the doctor can prescribe limitations on or a full retraction of the license (SWOV, 2015).

Often when older adults lose their ability to drive, they are thrust into a situation where they are forced to learn (or re-learn) a new form of movement such as mass transit, cycling, or another form of travel. To learn a new function at a later stage of life comes with a large set of challenges, not the least of which is the technological aspect that is so prevalent in today's world. It is important that there be inclusive options for elderly populations who must find a new way of getting around, otherwise these communities are at significant risk of social isolation.

2.5 Aging and Isolation

Social isolation and exclusion are a prevalent problem in many elderly communities. Kenyon et al. (2003) defines social exclusion in terms of transportation as such:

> The process by which people are prevented from participating in the economic, political and social life of the community because of reduced accessibility to opportunities, services, and social

> networks, due in whole or part to insufficient mobility in a society and environment built around the assumption of high mobility (p. 210).

From this definition, it can be argued that the level of social interaction acts as a parameter against which to measure how current transport options translate into wellbeing. Indeed, scholars have argued that social interaction is one of the main parameters that leads to overall wellbeing (Grossi et al, 2020). This definition of social exclusion came about over two decades ago, but it is still relevant. As our technologies develop, and the transportation systems with it, the capabilities required to maintain mobility shift as well. For the more adaptable in our population, this is not a limitation. In fact, these are the people who enjoy the greatest opportunity with changing systems. For those less adaptable among us, such as older adults and those with disabilities, changing systems represent a cumbersome barrier to deal with in the later stages of life.

Interacting with others and our environment is extremely important for our wellbeing for the duration of our lifetimes, and "social isolation is a real threat to the mental and physical health of the elderly population, leading to depression, self-harming (e.g., drug abuse, alcoholism, suicide) or self-neglecting behavior, a higher level of cognitive and/or physical disability, and increased mortality" (Chen & Schulz, 2016, p. 2). The older a person gets, the lower their level of wellbeing becomes, due in large part to their declining level of social interaction (City of Amsterdam, 2022). A lack of mobility contributes to isolation as a matter of practicality. Access to social opportunities is of almost equal importance for elderly communities as access to food or shelter.

For those communities that are situated in a fortunate position near a transit station, this proximity can be just the solution for continued access despite bodily decline (Shrestha et al., 2017). There remains the hurdle of cognitive ability to utilize a complex system of buses, and the hurdle of the first and last mile (getting from stop to final destination). A new form of road design could help to alleviate some of these barriers, however with new designs, there is always some type of learning curve. Demand-based systems can help to grant access to older communities, but this usually requires some sort of technical literacy. While there are some elderly people who are able to use technologies of today to access information, some still rely on printed information alone which can inhibit their ability to utilize a system that might otherwise help them (Shrestha et al., 2017). When it comes to utilizing transportation modes to generate new access conductors, understanding how they work is essential. Shrestha et al (2017) argues that, “information, especially regarding the accessibility of buses (vehicle, bus stop) is crucial to older people with mobility problems” (p. 349), however, this information is usually only accessible from an online resource, creating a hurdle for older adults trying to understand.

2.6 Dutch Regulations on Accessibility

The Netherlands is a signatory to the UN Convention on the Rights of Persons with Disabilities (UNCRPD) which means that they must comply with the United Nations regulations for accessibility. The UNCRPD lays out requirements for the physical accessibility for transportation infrastructures, specifying that stations be physically accessible, via ramps, elevators, and other infrastructures to minimize the physical capacity required to move, and well as cognitively accessible in terms of information and communication (route information, schedules, fares, maintenance schedules, and delays) for those with disabilities (United Nations, 2006). This cognitive access element can be related to use of technology, and as such

there is increasing interest in exploring the transport implications of inequalities in digital skills (Alonso González et al., 2022).

The main documents that provide guidelines for accessibility in the Netherlands are the Accessibility Handbook (Handboek voor Toegankelijkheid) and the corresponding Integrated Accessibility Standards (ITS). These standards have taken inspiration from other international accessibility measures such as the Americans with Disabilities Act (ADA) and are subsequently recognized internationally as equivalent criteria for accessibility (PBT, 2024). The goal of implementing the ITS is to create an accessible Netherlands. The ITS defines integrated accessibility as the ability to reach, enter, and use all functions and facilities as independently and equally as possible (PBT, 2024).

From these documents it seems that the Dutch transit systems and public spaces should be accessible to any person, regardless of ability. However, what comes into question is the functional (realized) access of these stations. The Council for the Environment and Infrastructure (RIL), which serves as the strategic advisory board for the Dutch government for topics on the physical environment and infrastructure, provides advice on accessibility design measures which are to be taken in the Netherlands. Their framework for accessibility focuses not on mobility, but on developing and maintaining a high level of broad prosperity (Brede-Welvert) in the population (RLI, 2021). Therefore, consideration is not only given to the level of built accommodations that exist in context, but rather how well those concessions achieve a given level of wellbeing for different user groups. Some of the strategies they suggest as a solution to the growing problem of traffic congestion include spacing mobility out over time, or better utilizing digital tools to provide accessibility alternatives (virtual attendance). Both of these solutions are conducive with a smart city vision but must also take into account the equity considerations for those who are not used to such high-tech solutions.

2.7 Smart Cities

Definition

The concept of smart cities is a relatively new one, focusing on the nexus of sustainability and new digital technologies. Therefore, coming up with a concrete definition poses a challenge. The concept focuses on shifting city infrastructures from the classic static model and instead utilizing a demand-based approach. This process relies heavily on digital data collection (from sensor-based systems) and aggregation to inform usage information. The data can come from sensors, meters, cameras, and other, unstructured data that provide real-time information to inform decision-making (Elgazzar & El-Gazzar, 2017). It can apply to practically any sector that utilizes resources such as water, electricity, waste management, communications, and mobility (Eremia et al., 2017). As city populations continue to grow, it is important that the urban environment adapts to become as efficient as possible, responding to monitored demand rather than interpreted predictions; this is the aim of the smart city idea. Smart cities are participatory by nature, incorporating data from users of various urban resources, so in theory, they are a democratic approach to determining the needs of the populous.

Opportunities

Smart cities offer a way to connect the urban environment and allow for harmonization between different sectors. Information and intelligence can be shared dynamically, which can allow different city works to optimize their use of resources and improve citizen's quality of life (Kar et al., 2019). For example, monitoring through sensors and global positioning systems can be used to identify what traffic routes are

most in demand at certain times of day, and then can supply the most sustainable modes (like electric buses) along those routes to optimize pollution reduction.

Implementation of technology in the city can also be seen as a way to open up the city to greater participatory planning, especially in the earlier stages of project development, allowing for a more bottom-up style of planning (Carvajal Bermúdez & König, 2022). Carvajal Bermúdez & König (2022) liken democratic "city-making" to technology hacking in the way that it requires rethinking the way established systems are used and acting rather than continue theorizing. This implementation of technology into the way cities work, they argue, encourages the participation of members of society in informal engagement methods as well as changing the way we view our urban spaces in the direction of more hybrid spaces. However, this approach assumes that all citizens have access to the appropriate technology to interact with such systems.

Limitations

Having access to smart devices is necessary to utilize many benefits of smart city technology, both for participatory purposes and for practical use of the systems. In order for a person to be "seen" by GPS or other digital tracking methods, they must carry a smart device. Those who do not, are left out of this aspect of the equation by default. Similarly, to use transportation services in a smart city context, users need access to smart devices to see available mobility services, check schedules, reserve rides, or even make informed decisions around mobility based on current congestion conditions (Golub et al., 2019, Young et al., 2019). In order to be able to take advantage of smart infrastructure, "the user must access various support systems and resources which form a smart mobility ecosystem, including internet and cell data, banking and credit accounts, all linked into an on-line and smartphone environment" (Golub et al., 2019, p. 3). All of these basic requirements for access in smart cities are less available to vulnerable communities like the elderly. According to a report conducted by the Center for Neighborhood Technology in the United States, lower income households (in the U.S) are 19-27% less likely to own smartphones than their higher-income counterparts (Young et al., 2019). This makes accessing the benefits of smart tech more challenging for these groups. For more intensive smart city projects that alter the level of accessibility for certain modes during different times of the day, this lack of knowledge availability could be detrimental to the functionality of their daily lives.

Kolotouchkina (2022) points out that smart city infrastructures often overlook the limitations that people with disabilities have when accessing this new kind of environment. She notes that disabled people make up a significant percentage of the global population, with the total number increasing every year as the world's population increases (Kolotouchkina, 2022) yet they are still often left out of the conversation when it comes to smart cities development. Along with this, there is the fact that people with intellectual disabilities, search for new information independently far less often than their conventionally-abled counterparts (Alfredsson Agren et al., 2020) and elderly users are similarly unwilling to learn new technology-related concepts that are not explicitly taught to them (Finkelstein et al., 2023). Smart tech often relies on users to do research or be willing to go to an information website to learn about recent technological advancements and so when users are either unable or unwilling to perform this act, they are limited in their capacity to engage with infrastructures, potentially limiting their mobility and access to opportunities (Young et al., 2019).

It is necessary and effective to mitigate a digital divide by offering digital inclusion workshop or training programs, such as "digital community ambassadors" or technical outreach to help older adults and other

marginalized population to get familiar with technologies they might be unfamiliar with (Boulos et al., 2015). This kind of outreach could help reduce a cognitive handicap for a large proportion of an affected population, however, would not solve the problem of a potential lack of access to smart devices at all.

2.8 Dynamic Road Space Allocation

Definition and Examples

One of the newer elements of smart cities is urban dynamic roads. Dynamic roads allocate space based on demand at different times rather than the more traditional one-size-fits-all-times approach. Stemming from the smart city concept, dynamic roads use sensors, GPS, and other big data collection methods to determine the demand and allocate space based on these results. Using this information, dynamic roads can be used to optimize the space used for transportation to maximum efficiency and sustainability. There are examples of this strategy being used in a highway-context, in the form of high occupancy vehicle lanes, truck lanes, and transit lanes on large thoroughfares (WSDOT, 2022). Implementing dynamic roads in an urban neighborhood context has different challenges and strategies associated with it and has limited implemented examples to be seen around the world.

The city of London experimented with dynamic road space allocation in 2017 with their Starling Crossing project (Umbrellium, 2017). In this project they temporarily installed a dynamic pedestrian crossing that was able to react "dynamically in real-time to different condition and is able to modify the patterns, layout, configuration, size and orientation of pedestrian crossings in order to prioritise pedestrian safety" (Umbrellium, 2017, p.1). Projects like this showcase how dynamic road space allocation in urban neighborhoods is a potential solution to issues that cities worldwide are increasingly contending with such as safety and congestion. Problems stemming from continued population growth, like a lack of space, that are exacerbated by car use, can be helped, or at least experimented with, by implementing a dynamic roads scheme. By using real-time demand to dictate road space changes, dynamic roads follow the principle that form follows function, and the road should follow the needs of the population, not the other way around (Umbrellium, 2017). They can also be a strategy to minimize car use by implementing dynamic strategies to prioritize other modes (such as bus lane prioritization). With dynamic roads, it is possible to reconfigure road space to allocate more space for public amenities that there is high demand for such as parks and outdoor seating, as well as maintain efficient transportation networks.

Another example of an urban dynamic road is one that has an intermittent bus lane during peak hours to facilitate bus efficiency over cars (Eichler, 2005). The same road could then have a lane of parked cars during off peak hours, or have this lane transformed into parklets for seating at nearby restaurants or bars, or even just general public sitting space (City of San Fransisco, 2020). See Figure 1 for a visual example of changing road uses during the day. This innovative strategy allows for cities to shift away from the static road-use system that we are accustomed to, and instead change the way roads are utilized, depending on the user demand and need at different times (Valença, et al. 2021). Just as a single mode cannot serve equally all kinds of people, a single road design is not efficient for all contexts, both spatial and temporal; therefore, having a variety of viable options for transportation is imperative. This strategy not only has the potential to increase the efficiency of street throughput, but also could allow more user mode choice in daily travel. However, because decisions must be made about which modes to prioritize at certain times of day, questions around equity arise. Consideration must be given to what population groups are gaining the most from these allocations versus who gets left out of the equation.

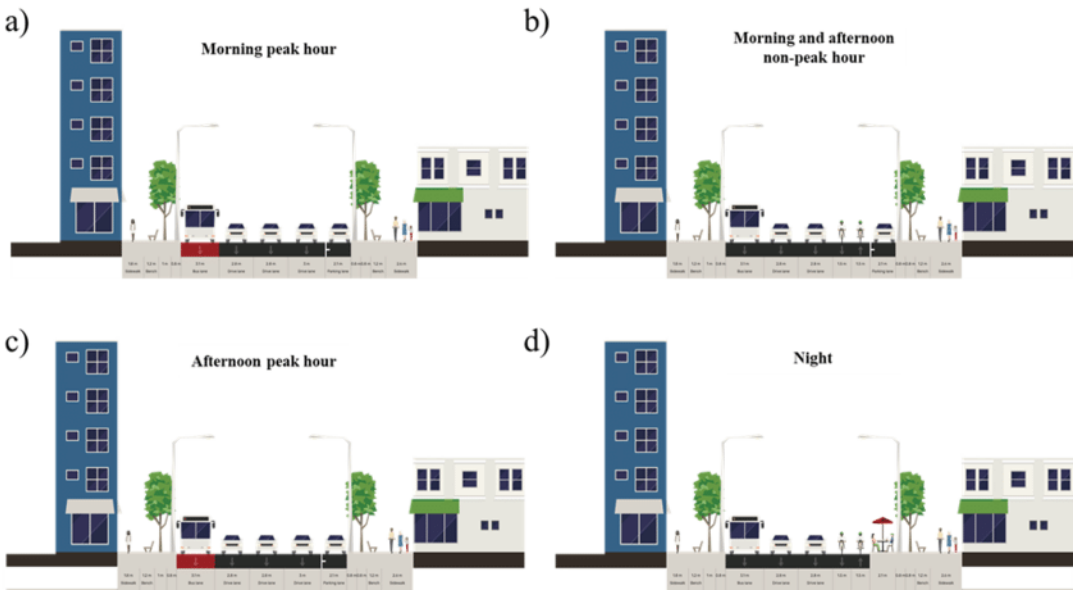


Figure 1:Examples of road configurations. Source: Valença, et al. (2021)

Equity Concerns: Technology

As decisions around space allocation are based on demand, the question must be considered; what methods are used for determining this demand? Since much of the population these days uses internet applications, "big data", gathered from social media, Point of Interest, and GPS, is most often utilized to find demand on a micro-scale (Valença et al., 2021). This kind of demand calculation overlooks the populations who do not use smart devices, such as the elderly. As a result, these groups do not find their needs reflected in this system and are forced to move in a world that was not designed for them.

It is assumed that when roads and transport modes shift in a neighborhood, it is vulnerable residents such as the elderly who are most affected. Higher-income, able-bodied residents have a much less elastic demand for things like transit, because if they need to, they often have access to a car if circumstances change unexpectedly (Wu et al., 2019). If the street design is changing to cater to different modes at certain times of day, the needs of vulnerable groups should be among those prioritized as they are often the least flexible. Dynamic roads are intended to increase street efficiency overall, but with intense time sensitivity and historical lack of influence low-income groups have, it is important to scrutinize the design choices with an eye towards equity.

The most immediate issue with dynamic road implementation is the problem of how users will be informed of the varying street uses and subsequent changes to mode access in certain areas. Steinfeld & Maisel (2012) suggest that a solution to the access of information problem of dynamic streets can be found by looking towards other standard transit access principles. Such principles include orientation, navigation, and destination information as well as information on the status of the system at any given time.

These principles work well for a static system of buses and routes but may need some adaptation to accommodate the innovative idea of dynamic roads which are intended to change with little to no notice. An initial solution might be to digitize the information systems. Increasingly, “mobile phone applications are influencing how people move by indicating traffic routes that have shorter travel times” (Valença et

al., 2023, p. 1). This kind of information dispersal is useful for informing the public about unpredictable events as it can be done almost instantaneously. It is similarly useful for dynamic roads due to their unpredictable nature as well. Using smart devices to disperse vital travel information may be satisfactory for a general population who has access to a smart device, but it assumes the capability of technological literacy and leaves out consideration for those without.

Kar et al. (2019), notes that technology is often seen as the goal, rather than the means for making our cities accessible and sustainable. In order to avoid falling into this assumption, careful consideration must be given to the practicalities of making it fit within the capability framework of the surrounding community. Kar et al. (2019) highlights a need to "cater to inclusiveness from the perspectives of digital, social, economic, professional, and personal development" (p. 496). For roads that change dynamically, it is necessary to have a strategy that disperses route information in a way that is accessible to everyone. In the world that most people are used to, without dynamic streets, roads are predictable, and therefore route planning, accessible. To maintain the usability and safety of the transportation network, efforts need to be made to ensure some level of predictability with the systems (ITF, 2022).

Equity Concerns: Impermanent Infrastructure

Accessibility concerns with dynamic streets are not only limited to issues surrounding technological prowess. There are also limitations surrounding the necessary impermanence of dynamic road infrastructures. The dynamicity of these roads comes from their ability to change relatively easily, which is enabled by a lack of permanent structures (WSDOT, 2022). However, many road designs are safest when they provide a solid, immovable structure which protects more vulnerable road users from high-speed vehicles (Department for Transport, 2020). With cycling infrastructure for instance, often, the more permanent the built infrastructure is, the higher quality it is, allowing for more people to use it comfortably (Dutch Cycling Embassy, 2022). Lower quality cycling infrastructure creates safety issues which can in turn increase the capabilities needed to access the bike as a reliable mode of transportation. For people with disabilities, this could mean that they cannot utilize bike infrastructure that has the potential to increase their access to opportunities in the urban environment.

This impermanence also has the unintended potential to shift people towards the car, instead of away from it. Sheller and Urry (2000) argue that the automobile coerces people into an intense flexibility, "force[ing] people to juggle tiny fragments of time so as to deal with the temporal and spatial constraints that it itself generates. [It] structure[es] and constrain[s] the 'users' of cars to live their lives in particular spatially stretched and time compressed ways" (p. 744). Since car driving has become the status quo against which we measure all other travel strategies, any variation from the independence of a privately owned motor vehicle is seen as a limitation on this perceived freedom. With the addition of the temporal constraint from the road use side, it shifts the reliability of the road, which pushes users towards the familiar reliability that a car provides. Dynamic streets are intended to be optimized to meet the demand of the users, so if the variability of the street space pushes more people into their cars, then the roads may once again be designed with cars at the center.

On the other hand, Valença et al. (2021) argues that dynamic street allocation strategies can be very effective in demonstrating the attractiveness of a "modal shift away from car, safety, physical activity and increase in social interactions" (pp. 3-4). The advantage being that planners do not have to implement an entirely new and permanent streetscape. In this way, "dynamic road space allocation can be a strategy for

policy makers to introduce the reallocation of space without contesting the space for the automobile in the first moment" (Valença et al., 2021, p. 10). This helps to garner public support for more radical street redesigns. A softer launch of innovative road designs helps to acclimatize users before permanent implementation. Bach et al. (2018) puts it perfectly, saying "temporary reuse of spaces is often an opportunity to display a vision of a city's future, a glance into the crystal ball" (p. 95). Impermanence is a useful tool for experimenting with strategies to increase the mobility of a particular population. Because of its impermanence, there is space for trial and error in design. The impermanence of urban design is often frustrating to planners and users alike, however new ideas in dynamic road space allocation aim to harness this impermanence to create urban spaces that ebb and flow with the rhythms of human life.

In many cities today, often there is no real choice for the everyday commuter. They must "choose" between a car (which comes with expenses and negative health effects) or a mode which lacks sufficient infrastructure to compete with the car (Gössling, 2016). For example, a bus route or bikeway might not connect the traveler sufficiently to their destination, or might put the person in unreasonable danger during the commute, leaving only one viable option: the car. Such modes are not equally accessible to everyone, nor does every person want to choose the car as their main mode of travel. Changing the status quo of transportation options in the city is politically challenging: "Existing transport systems represent 'order' and change 'chaos'" (Gössling, 2016, p. 6), but dynamic roads can help to ease this perception. If the ability to alter the environment on a temporal basis to better suit demand, then the act of change becomes less demonized and not only produces a more efficient traffic scenario, but also a more just one.

There are no examples yet of any truly dynamic urban roads. However, there have been dynamic elements implemented in various cities around the world. The first instances of dynamic roads began with bus lanes that shift lane priority during different times of the day depending on the level of car traffic (Valença et al., 2021). These shifting bus lanes automatically grant priority access to buses when they are present, but do not interfere with the natural lane use during times when buses are not passing through the area. As a result, they reduce bus travel time without severely impacting the rest of the traffic flow (Othman et al., 2022). There have also been developments in the reappropriation of street space for public use in the form of parklets. First developed in San Francisco, USA, parklets transform street parking spaces into seating areas with benches and oftentimes, light vegetation (City of San Francisco, 2020). The advantage of the parklets is that they are temporary and can be moved if the situation requires it. This means that a parklet could be installed during off-peak hours when road demand is low, and removed when there is high traffic flow. Parklets are very useful for revitalizing underutilized urban areas, providing a gathering space for the surrounding community without much investment from the city (Carvajal Bermúdez & König, 2022). As of yet, there are no examples of these elements being used in a dynamic fashion, but they are part of the proposed ways roads can be altered dynamically to keep up with an ever-changing demand.

Dynamic roads are still a widely experimental model and thus precautions must be taken to ensure that equity is taken into account in its implementation.

Problem Definition, Knowledge Gap, and Research Questions

This section lays out the aim for this thesis project; defining the problem at hand, the knowledge gap in the literature, and the specific questions which this research strives to answer.

While dynamic roads seem like a great solution to urban space scarcity there are still considerations to be taken before planners can start converting static roads into dynamic ones. A major concern is the unpredictability of a road that changes dynamically throughout the day. The constant changing of a road means that in order to have accurate information about routes, constant updates must be given to potential users. This feat is impossible without the use of technology and smart devices. For those who are not technologically savvy, this high-tech solution could pose a challenge as they rely on a user's ability to use a smart device to access information on unpredictable routes. Another concern is that dynamic roads tend to take space away from car users, at least at certain times of day, and in spaces that were designed around the automobile and its corresponding infrastructure, this can pose accessibility challenges.

3.1 Problem Definition

Historically, urban environments have been configured to prioritize cars, granting them the most street space, even though they are not the most space efficient, nor the most environmentally friendly, and they contribute to furthering many urban woes (Guzman, 2021). Even in cities that were not originally designed around cars, such as Amsterdam, cars have managed to poison a large portion of our precious urban spaces. Motorized vehicles have been in control of our urban environments for so long that this fact has faded into the background of our consciousness. But now, as more scholars begin to look at the equity implications of different transportation strategies, it is becoming ever more obvious that we must change the way we use the precious resource of space in our cities.

Dynamic roads have potential to dramatically change the way we interact with our cities and allocate space to different uses, but we must be careful not to implement them with a one-size-fits-all strategy. As with any new infrastructure, dynamic spaces must be tailored to the existing environment, in order to improve, rather than replace the existing dynamics. If planners implement dynamic roads without taking into consideration the abilities of all to utilize it, the effect will be detrimental to the accessibility of the affected area.

As technologies change in our cities and transportation networks, the competencies needed to adapt with them are also changing. Vulnerable groups such as elderly people are at particular risk of losing access to transportation and subsequent opportunities because of their lower technological literacy (Finkelstein et al., 2023). In today's world, technology is extremely important for moving around (especially in an urban environment) yet, many devices are too complex for elderly users to use (Iancu & Iancu, 2020). In a context such as dynamic roads, technology is especially important in order to access the base requirements of movement.

The goal of dynamic road space allocation is to make city streets more efficient as well as create new opportunities in underutilized spaces, however these efforts are ineffectual if they do not cater to all groups in society. Lucas & Jones (2012) notes that there is strong evidence that the uneven allocation of benefits and burdens of transportation systems "reduce people's ability to fully participate in society and can lead to their social exclusion" (p. 1). It is imperative that innovation in dynamic street design actively enhance accessibility to urban amenities for marginalized communities as well as take their immediate

needs into account. Therefore, dynamic roads pose a challenge for cities as a whole if their ambition is to create equal access for all.

3.2 Knowledge Gap

Despite there being extensive research on justice in a transportation context, there is little development on the implications of dynamic road space allocation on the accessibility levels of elderly populations. Dynamic roads are still quite a new subject and as such need further research into the potential effects of their implementation. This thesis will attempt to address this gap by determining the current capabilities of elderly transportation infrastructure users and contrasting these to the capabilities required to effectively utilize dynamic roads.

Most studies that investigate the potential effectiveness of dynamic road space allocation are focused on the diversity of land uses, rather than diversity of population, theorizing on the various ways the land could be used in a given situation. New innovations must be place-specific as well as community-specific in their implementation. This means tailoring new designs to the needs of the people who live in the community rather than just to the existing built environment. In order to achieve this, planners need to be aware of what the current limitations and capabilities are of elderly transportation infrastructure users, as well as how these factors interact with their ability to access desired opportunities in the city (Lucas & Jones, 2012).

3.3 Research Questions

Responding to these points, this thesis aims to determine the most vital modes for elderly residents to maintain their access to opportunities in the city and their overall wellbeing at the later stages of life. To do so I will attempt to answer the primary research question:

How might dynamic roads affect accessibility for elderly communities?

To answer this question, I explored an elderly neighborhood in Amsterdam to contextualize my results and answer two sub questions. The first of these sub questions is:

- What are the capabilities of the elderly population that dictate their access to opportunities via transportation?

By answering this question, I can identify what the limitations are for the population, and what infrastructures will be conducive (or not) for the maintenance of their accessibility. The second sub question allows me to further put the question into context by relating the capabilities to the specific equity and access goals of the city of Amsterdam. The question is as follows:

- Does the implementation of dynamic roads align with Amsterdam's equity and access goals?

By answering these questions, I assess if the implementation of dynamic roads is conducive for achieving the city's goals of equity and access for elderly communities.

Theoretical Background

4.1 Definition of Justice

Distributive Justice

Justice can be defined in numerous ways, but my understanding of the term stems from John Rawls' (1999) theory of distributive justice. Rafael Pereira (2017), interprets Rawls notion of distributive justice as such: "Justice is not about whether some people enjoy greater accessibility than others, but about how institutions and policies deal with such inequalities in order to minimize inequality of opportunities" (p. 181). Instead of focusing on material equality, Rawls' ideas are formulated around equity of opportunity, deriving from an egalitarian notion of justice (Rawls, 1999). His ideals stem from an understanding of fairness as meaning all free citizens hold equal basic rights, granting equal access to opportunities However, where societal inequalities exist, certain advantages and resources should be allocated to different groups according to their needs in order to achieve a world where everyone has the opportunity to succeed. In interpreting Rawls, Pereira (2017), insists that "not all inequality is unfair and, in fact, fairness comes sometimes at the price of treating people differently according to their differences and even limiting some individual liberties (p. 171). Therefore, when it comes to dynamic road implementation, it must be context specific, and cater to the surrounding populations, allowing for them to experience the most accessibility possible. This means that different neighborhoods will receive differing levels of infrastructure development and road space allocation.

Transport Justice

The standard right-of-way of the street gives a good example of how justice comes into play in transport. In many cases, "street-level mobility systems are 'rivalrous', meaning that they can only enable mobility for some by requiring the simultaneous immobility of others" (Petzer et al., 2021, p. 6). This means that usually, if one set of users will gain an advantage in a transportation system, (like increased road space allocated for bus-only lanes, as an example), then another set of users will lose some advantage (less space for cars and slower transit times with this mode). In order to maintain justice while making changes to the network, priority must be given to granting the least advantaged community the most advantage with each change. If this is inherently true of most mobility networks and systems, then in keeping with Rawls' approach, the instances of the above-mentioned immobility should apply in proportion to those who already are at an advantage in society, granting "right of way" to more vulnerable groups who by default have a more challenging time accessing opportunities.

Access to all opportunities relies on a person's ability to move effectively and efficiently though the world. Access is the catalyst that makes all other activities possible. Transport justice depends on the traveler's ability to make a conscious choice about the mode they choose within the city. If no real choice exists, then transport justice is low. "It is not only the end result… that is important… but whether people can freely choose the 'beings' and 'doings' they value, and whether they are able to achieve their vision of 'the good life'" (Randal et al., 2020, p. 6). Different people have different preferences and demands for the modes that get them from place to place. This means planners must tailor transportation options to the needs and capabilities of the surrounding community so that they can reasonably choose the mode that best suits their lifestyle and needs.

Just because there is one mode that generally is accessible to a certain demographic, this does not mean that they should be confined to the limitations of this one mode. Choice is often equally important in

granting freedoms than static access from point A to point B is. If granted the freedom to choose between several equally viable modes to access opportunities, then justice in terms of transport is achieved.

The viability of accessing each option is another element of justice. When a government takes on goals surrounding equity, they take on the responsibility to provide for options that allow for realization of this equity, including transportation options to access urban amenities (United Nations, 2006).

Governments often take on congruent goals around equity and sustainability, urging individuals to make choices in their daily lives, including transportation mode that is in line with achieving these goals. However, the viability of using more sustainable modes of transportation is called into question. There are arguments that the lack of utilization of certain modes is due in large part to personal preferences, but "it is not always possible to tease out how much inequality in travel behavior arises from individuals' tastes and preferences (voluntary choice) and from contextual constraints outside individual control" (Pereira, 2017, p. 177). It is important to differentiate the two because they must be approached with different strategies if the goal is to allow more people to access daily opportunity via dynamic roads. Questions arise around how this "personal preference" comes to be. Can it really fall to personal choice if all options are not equally accessible? By implementing the infrastructures that make more sustainable modes more attractive, planners and cities can achieve both their sustainability and equity goals in one fell swoop. Road design is one such infrastructure that plays a huge role in dictating what modes people will choose and as such, "dynamic road space allocation can … influence the road space not only to generate but also to switch trips to different transport modes" (Valença et al., 2021, p. 7).

Measuring viability is often challenging, but by using a capability approach planners can determine the context-specific elements that either inhibit or provide for the viability of transportation strategies. Especially when working with vulnerable groups such as the elderly, it is important to maintain avenues of equitable access by understanding their abilities and limitations so that they do not succumb to the woes of urban isolation which are so prevalent in the elderly populations of inaccessible cities (Cui, 2017). Governments should not only provide the necessary physical resources and infrastructures, but also analyze and understand how different designs and resources affect the ability of the population to move and achieve mental and physical wellbeing.

Difference Principle

Often, new ideas in transportation leave out considerations for more marginalized groups, allocating the costs and benefits unfairly, resulting in the "people who are least able to use transport networks bearing the greatest costs, both economic and otherwise" (Randal et al., 2020, p. 3). To address this, Rawls is again referenced. Rawls' Difference Principle emphasizes the importance of arranging social and economic inequalities so that they grant advantage to the most disadvantaged groups (Rawls, 1999). When applied to transportation, the principle, "implies that fair transport policies are those that improve access levels particularly for the most disadvantaged in society if there is a differential, rather than universal, effect" (Randal et al., 2020, p. 7). When any change to a transport system is enacted, "there may be system users who benefit from the change, users who lose as a result of the change, and non-users who may be either adversely or beneficially affected by the change" (Richardson et al., 1995, p. 20), the aim of transport justice is to make sure it is not disproportionately vulnerable users who are part of that second group.

Pendersen (2020) suggests that Amartya Sen's capabilities approach (Sen, 1993, 2005) grants a set of indicators to look for during comparisons to determine if social inequality exists in a specific context,

allowing planners to make informed design decisions that help enhance accessibility. The words “specific context” are used deliberately here as different population groups have different capabilities and therefore need differing infrastructure designs in order to achieve access. When the appropriate level of infrastructure is provided, a person’s capabilities are expanded: they are at liberty to make a choice regarding their mobility and how they wish to access opportunities. Pendersen (2020), argues that when this is achieved, responsibility for the outcome of these choices falls to the user. However, this is not always the case. Responsibility for justice remains with the designers of the roads until context-specific solutions to accessibility struggles for vulnerable groups are developed. This means that even after a policy or infrastructure has been implemented, there remains responsibility for the designers and implementers to continue to monitor and make sure that the infrastructure reaches the equity and accessibility goals that it set out to achieve.

4.2 Capability Approach

I will conduct my research using the conceptual framework of Amartya Sen's capability approach (Sen, 1993, 2005). The capabilities approach is highly contextual, focusing on what elements each individual needs to enable them to access desired opportunities. Utilizing elements from Rawl’s Theory of Justice (1999), Sen's capabilities approach expands on previous economic theories surrounding wellbeing, which historically confine their focus to incomes, choices, and feelings (Gasper, 1997). Where these economic theories focus on material equality between persons and groups, Sen's capability approach follows Rawls in focusing on the equality of access to opportunities (Sen, 2005). Assessing access to opportunities is a way to understand the experienced equity of wellbeing in an urban environment between groups. High levels of accessibility are hypothesized to lead to greater feeling of wellbeing in a community. However, access varies for different groups. In transport planning, diversity of demands is often overlooked, catering to a set of capabilities that is too narrow to adequately serve the different needs of individuals. For example, if a road is designed to shift to accommodate demand, then by nature it only caters to the user group with the greatest numbers (a utilitarian approach), leaving out the demands of the user groups who do not fall into this category. The largest group is often commuters during peak hours, which leaves out the needs of those who do not follow regular workday travel patterns. Their needs are different than those of the commuters, but are not reflected in the road allocation system. The capability approach helps to describe the differences in experiences between different demographic and geographical populations. Sen (2005, p. 154) notes that,

> The capability approach can help to identify the possibility that two persons can have very different substantial opportunities even when they have exactly the same set of means: for example, a disabled person can do far less than an able-bodied person can, with exactly the same income and other ‘primary goods’. The disabled person cannot, thus, be judged to be equally advantaged — with the same opportunities — as the person without any physical handicap but with the same set of means or instruments.

This reinforces the idea that opportunities, and the capabilities required to reach them are extremely context specific, right down to the individual scale. Martha Nussbaum agrees, focusing on the “separateness” of individuals, indicating that you cannot expect the same resources to grant the same level of opportunity to different people (Nussbaum, 2000). Essentially, equality of resources does not necessarily result in social equity or equality of access to opportunities. More considerations and factors must be examined in public policy; if not on an individual scale, then at least on a community one. It is for

this reason that Sen avoids setting a list of fundamental capabilities. He argues that in creating a fixed list of capabilities, theorists are limiting the potential for public opinion to influence what should be included in the list (Sen, 2005). Therefore, through this thesis, I aim to gain an understanding of what capabilities exist and are required for an elderly population to use different transportation modes to reach their desired opportunities in a city.

Although originally conceptualized by Sen, other scholars have contributed extensively to the practical development of capabilities. Nussbaum for instance, disagrees with Sen, and argues that a practical list of capabilities would be useful in developing guidelines for different levels of governments to follow when planning the urban environment. She likens listed capabilities to a constitution of rights; to be aspirational and provide guidance, but to be open to interpretation for specific contexts (Nussbaum, 2016). Having a clear set of capabilities would make it simpler for municipalities to specify their infrastructure projects to the needs of the community.

Using the capabilities approach to understand the needs of a community before infrastructure changes can be enormously helpful in achieving equity goals. However, as capabilities are so context-specific, it would still be necessary to complete a study on each impacted community to understand their capacities. As a result, having a broad list of capabilities could be misleading for municipalities and result in projects that do not match the needs of the surrounding community (Sen, 2005).

In Amsterdam, there is increasing focus on achieving goals around environmental sustainability and equity (City of Amsterdam, 2022). The city aims to limit car use within city borders among other goals (Gemeente Amsterdam, 2016). However, they must keep in mind that "policy should extend the range of things that people can do rather than prescribe what they should do since peoples tastes differ" (Anand et al., 2007, p. 55). This means that when implementing new designs in cities, consideration must be given, not only to activities that city governments and stakeholders value (such as economic development, or achievement of sustainability targets), but to the desires and needs of the surrounding communities. A good design will help to meet these goals if they provide sustainable transportation as a way to meet the desires and needs of the community. A capability approach to evaluating plans in the context of the surrounding community helps to derive what exactly these desires and needs are, and how the built environment can help facilitate access to them. Anand et al. (2007) points out that,

> Many utilitarians claim that we should prioritize only those sources of disadvantage to which individuals do not adapt, whilst proponents of the capabilities viewpoint out that many women have adapted to inequities in labor markets but that this is not a reason to fail to promote equality of opportunity (p. 58).

The utilitarian perspective is an ends-justify-the-means philosophy in which if the end result is that of maximum achieved wellbeing for the greatest number of people, then the manner in which the population gets there is of no matter (Scarre, 2020). In the example above, women have been forced to overcome inequalities on their own, rather than through changes in policies that actively help them to break into the job market. The end result may be similar, but along the way, these women would have faced extreme challenge and hardship, and many still excluded, where another process could have helped them.

Therefore, the policymakers should not rely on the ability of a disadvantaged population to adapt to less-than-ideal circumstances as a reason to continue to promote policy that restricts their present capabilities. This kind of policy justification can be seen in the case of an elderly population, where there is potential

for them to learn and adapt to new technologies such as smart phones and other devices. However, these policies do not take into account that this group will not inherently be able to use technology in the same way that younger populations can. This is a problem that is not specific to the generations present now. Just as an older generation now cannot adapt to the new technologies of this time, in the future, there will be technology that those who are young now will struggle with. There must be a precedent for designing cities for the populations who use them currently, or we risk isolating those who built the world that we know today. Cities should not be designed to rely on access to smart technology and the know-how to use it in order to reach desired and vital opportunities, since not everyone can use these technologies effectively.

In order to measure access of opportunities, I take inspiration from Giovanni Vecchio and Karel Martens (2021) conceptual framework, derived from Sen and Nussbaum's capabilities approach. Their framework focuses on five elements: resources, conversion factors, capabilities, functionings, and finally wellbeing (Vecchio & Martens, 2021). These elements come together to determine a person's overall mobility (their ability to be mobile) and their capacity to translate this mobility into something useful (accessing opportunities in the urban environment). My framework does the same, except alters the role of wellbeing in the relationship. In my understanding, wellbeing is determined by the capabilities (the potential accessibility) and the functionings (the realized access). Figure 2 visually represents the interdependencies between the categories, demonstrating how they feed and influence each other.

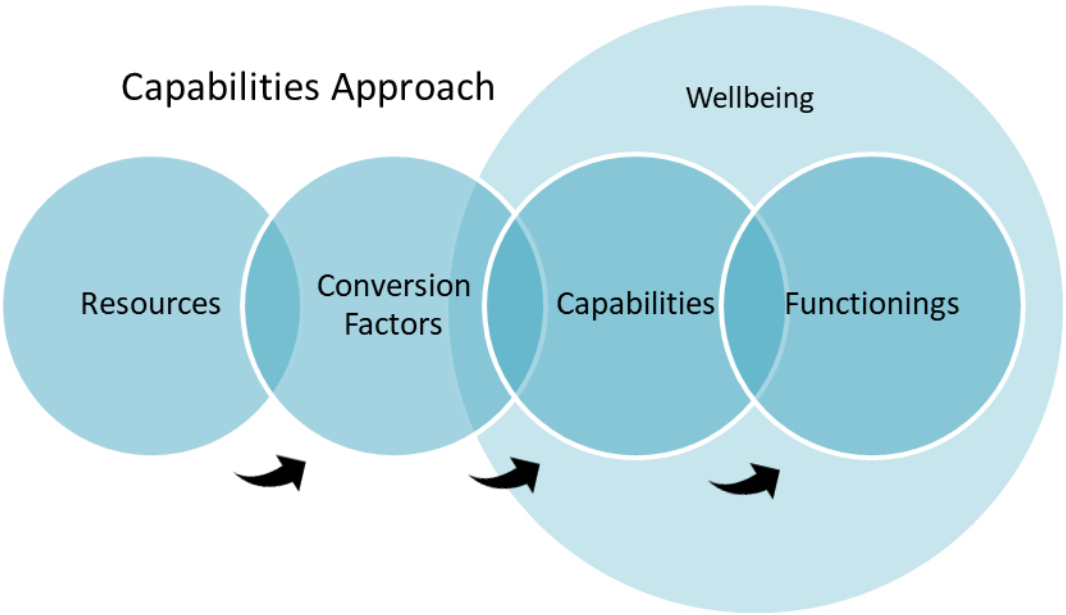


Figure 2: Capabilites appraoch visualization. Source: Author

Resources

Resources are the physical objects that a person uses in order to gain access to certain mobility options. They are broken down into three categories by Vecchio and Martens (2021): Private mobility resources, publicly available mobility resources, and activity opportunities. *Private mobility resources* are owned by

an individual. It could be a car, bicycle, transport pass, private parking space, etc. (Vecchio & Martens, 2021). *Publicly available mobility resources* are openly available, provided by the public sector, the market, or otherwise (Vecchio & Martens, 2021). Everyone is dependent on publicly available mobility resources in one way or another. Even if they choose to operate a car, they still depend on public streets, public parking, and other public infrastructures to support their mobility choices. *Activity opportunities* are the surrounding land use systems. Activity opportunities are all the potential opportunities that the surrounding city has available, regardless of residents' ability to reach them. That includes employment, buying groceries, meeting people, enjoying leisure time, etc. (Vecchio & Martens, 2021). Not all activity opportunities are valued by all people, which is where conversion factors come into play.

Conversion Factors

Conversion factors represent the potential for a person to turn resources into the freedom to travel and access opportunities (Vecchio & Martens, 2021). A person's income, ability, concern for personal safety, ability to use technology, and confidence in using various modes, are just a few factors that determine a person's ability to use the resources available to gain access to opportunities (Vecchio & Martens, 2021). The combination of resources and conversion factors is what dictates a person's mobility. However, conversion factors are the most dynamic element and can change dramatically with a person's skill level, perceptions of and knowledge about opportunities. A person's lifestyle changes as they age, and different opportunities become available as their skillset and temporal schedule shift (Vecchio & Martens, 2021). Conversion factors are highly specific to individuals, and even at the individual level are subject to great variance. For example, lower-income people are much more influenced by the presence of public transportation options on their travel patterns than higher-income people because their capabilities for accessing more costly modes is different (Wu et al., 2019). It is impossible to account for all the variables that individual experiences, so some assumptions must be made, generalizing observed trends for a population (Vecchio & Martens, 2021). A focus on conversion factors when developing a policy framework enables residents to define what matters most to them and the community at large (Randal et al., 2020). In this way, policy can be specific to community and individual needs which can fluctuate dramatically across populations.

Conversion factors change both as residents age, and as the environment around them changes. The two frequently happen in tandem, creating a complex web of challenges for older residents. The changing conversion factors for these groups could consist of; declining physical ability, limited technological literacy, visual impairments, or hearing loss. However, not all conversion factors associated with the elderly are negative. They also enjoy a more flexible schedule as they are not tied to a workday commute, which grants them a temporal conversion factor and opens up more mobility options. The challenge is making sure that the developing road designs take these prevalent conversion factors into account, especially when working around elderly dense communities.

Capabilities

Capabilities are the combination of resources and conversion factors that become a person's level of accessibility. The capability of access leads to the achievement of different combinations of functionings that enable freedom of opportunity (Sen, 2005). Access is the gateway to all opportunities, so focusing on granting this capability first is vital. The more conversion factors that are considered in an accessibility study, the more accurate that study will be in determining the overall accessibility that an individual experiences (Vecchio & Martens, 2021). Capabilities represent the potential to utilize available conversion

factors to generate opportunities. Essentially curating a menu of mobility options that lead to specific opportunities and destinations.

Functionings

Functionings represent the achieved access to an opportunity. Where capabilities represent the potential ability of an individual to achieve an opportunity, the functioning is what happens when they make the choice to select a capability and use their conversion factors to transform it into an opportunity (Sen, 1985). Functionings are often the easiest element to measure because they are observable and tangible to users and researchers alike. They are an essential element for evaluating a person's quality of life. However, achieved functionings only reflect a percentage of the capabilities available to a person, and therefore do not represent the whole picture of access. Achieved functionings are extremely dependent on the individual who accesses them. Achieving them depends on many social and personal factors that are specific to a given situation and context (Clark, 2005).

Wellbeing

In Vecchio and Martins' (2021) framework, wellbeing is determined by the level accessibility enjoyed by an individual and the achieved functionings that result. It is related to the level of choice that an individual enjoys. It is important both that an individual has the ability to choose their preferred mode of travel from a selection of viable options, as well as be able to choose opportunities to take advantage of. According to Vecchio and Martens (2021), "even if the person does not always choose that "best" option, the freedom embodied in a large choice set is in itself likely to enhance wellbeing" (p. 845). Wellbeing is often associated with happiness and life satisfaction as well as physical and mental health. In terms of measuring access, wellbeing is the reasonable ability to access all desired opportunities in an urban context. In theory, the more capabilities that are open to an individual, the more life satisfaction they can derive from this set of options. In this study, wellbeing is indicated by the level of social interaction that each individual engages in, and their subsequent satisfaction with this experience. Social connectedness is said to be one of the main contributors to wellbeing in a person (Grossi et al., 2020).

Methodology

5.1 Research Strategy

My research will utilize the capability approach's five-part assessment criteria (henceforth referred to collectively as "capabilities") to conduct a survey for understanding what capabilities elderly users possess regarding transportation (See Appendix A: Survey). I will compare these capabilities to the proposed changes that dynamic roads will impose and determine if they are compatible to achieve Amsterdam's equity and accessibility goals. My methods will include both qualitative and quantitative research, utilizing surveys with residents and document review.

Transportation research, especially around user choice and preference can be very nuanced, which is why a mixed-methods approach is optimal (Książkiewicz, 2012). Transportation is part of everyday life for nearly everyone, and is entrenched in many other aspects of life, acting as a gateway to opportunity. Transportation networks in the scope of urban planning have to balance the needs and desires from a multitude of actors and stakeholders, not least of which is citizens. In order to fully understand the dynamics between all of these factors, we must take a holistic approach. For this reason, I determine firsthand, how road users prefer to move, when they do it, and for what reason. This is the quantitative side. On the qualitative side, I determine what the goals for equity look like for the city of Amsterdam, and relate these two, in order to make a judgement on if the implementation of a dynamic road project would further these goals or hinder them.

First, I will administer surveys to collect quantitative data that will determine what the current capabilities are that the elderly community possess surrounding their current mobility. Second, I will conduct qualitative review of the documents related to the Amsterdam Zuid station update. This will allow me to discover if these plans align with the capabilities that an elderly population possesses, discovered in the survey. I will then discuss if the implementation of dynamic roads aligns with the surveyed population's ability to access opportunities and if this implementation will align with the goals that the Amsterdam municipality has for equity and inclusion.

My analysis will utilize quantitative statistical methods to draw initial conclusions from the survey data, and then be compared to a qualitative analysis of the proposed plans for changes to the Zuidas area. In this way, I will be able to discuss the implication of dynamic roads measures on the neighboring elderly community in Buitenveldert.

5.2 Case Study

The case will focus on determining what the current travel trends and capabilities are of elderly in the Buitenveldert neighborhood. It is important to gain an understanding of the capabilities of this population as they are located close to the site of a proposed implementation of dynamic roads.

The Amsterdam Zuid station and the area around it (referred to collectively as Zuidas) are undergoing a series of projects to make them more accessible and optimize use of the space. One of the proposed changes for the surrounding area is the incorporation of dynamic roads. Since access to the roads surrounding the station is vital for reaching many opportunities in Amsterdam, it is necessary to know how it will affect the elderly users in the area.

Buitenveldert Area

Buitenveldert is the closest residential neighborhood to the Zuid station, located just south of the business district surrounding the station. There is a good assortment of amenities in their area, from greenspace (Gijsbrecht van Aemstelpark), to shopping (Gelderlandplein shopping center), and transit options (both tram and bus lines, as well as access to the Zuid station within walking distance). It is assumed for this reason that residents in the area enjoy a good quality of life.

Buitenveldert is known to house one of the highest concentrations of older adults in Amsterdam, with 28% of residents over the age of 65 (Central Bureau of Statistics, 2023c). Located so close to the Zuid station, residents in this area have an implicit interest in the developments happening there. Because there is such a high density of elderly in the area, this case study is ideal for evaluating potential equity implications of smart and sustainable design on elderly populations.

The changes taking place at the Zuid station have the potential to significantly change the way traffic and people flow in and out of the area, so taking the needs of the surrounding population into consideration is vital. The mobility of a population is a delicate element to maneuver, and this is especially true for elderly populations who are likely unfamiliar with the technologies necessary to use some infrastructures (Vaportzis et al., 2017). A deep understanding of their capabilities and limitations is necessary to achieve before implementing a new design (Djoub, 2013).

Background on Amsterdam Zuid Station Project

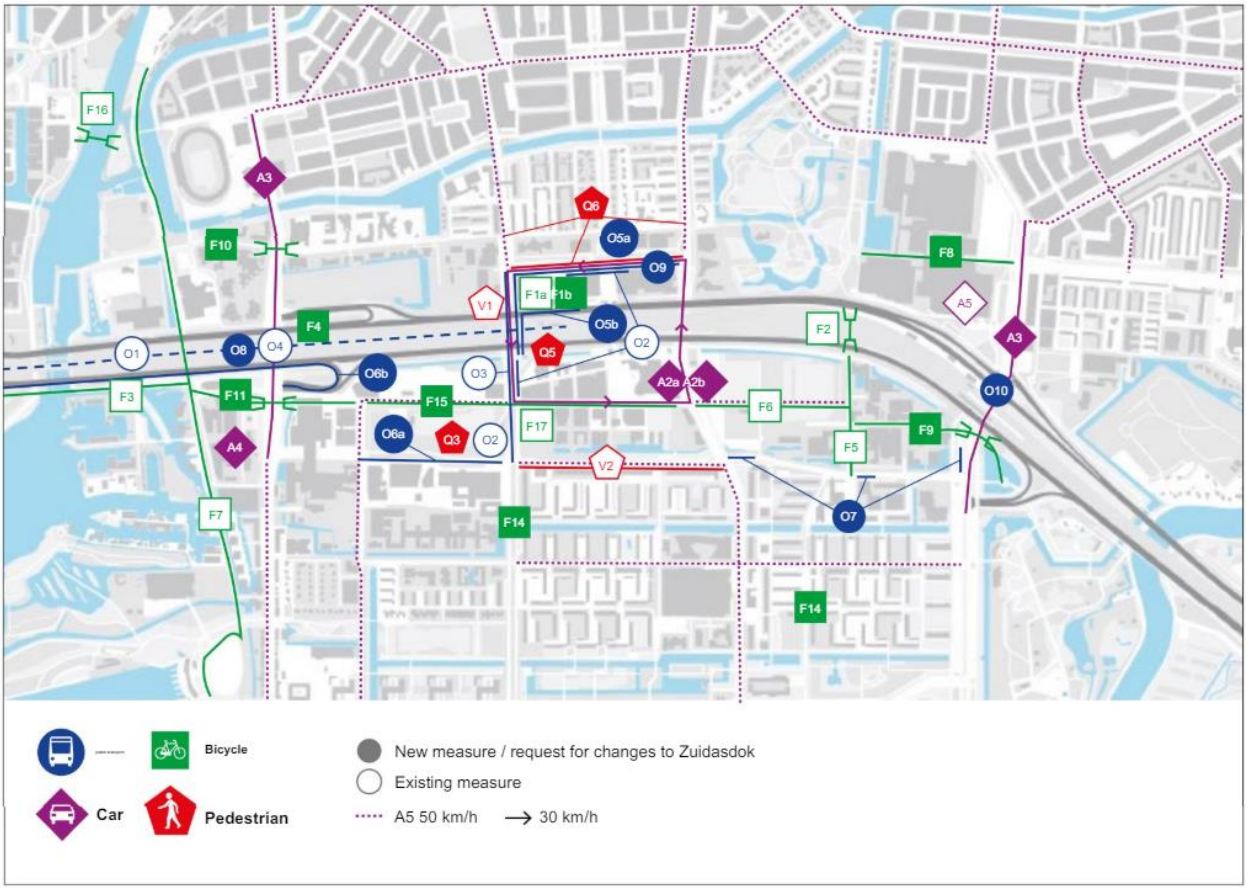
The municipality of Amsterdam has undertaken many projects to revitalize the Zuidas area, hoping to create, what it calls a “second center” of Amsterdam (Gemeente Amsterdam, 2023). The Zuidas area comprises of the Amsterdam Zuid station, along with the area immediately surrounding it (shown in Map 1). It is rapidly growing with new businesses and residences being developed and competition for space is ramping up (Amsterdam Zuidas, 2023, 2024). With many commuters coming to the area from all over the city and country, it is a pole for innovation, making it ripe for new infrastructure development. New construction in the area includes new buildings, but a large focus is also on improving the road and public space to be of higher quality, safer, more inclusive, accessible, and aesthetically appealing (Amsterdam Zuidas, 2023). The municipality of Amsterdam has prioritized updating the area surrounding the train station in hopes to increase accessibility as well as encourage more diverse uses for the space such as public gathering, rather than for it to simply function as a gateway to other destinations (Gemeente Amsterdam, 2023).

As the Amsterdam Zuid station is a main transit node in the south of Amsterdam, it is vital to maintain and improve accessibility as these changes take place. Currently, accessibility to the station from the surrounding area is lacking and there exists a barrier between the residential neighborhoods to the south and the station, in the form of an unwelcoming high-rise business district. Just by taking a quick walk through the area, it is apparent that the area immediately south of the station caters to the automobile, is hostile to pedestrians, and is somewhere in between for cyclists.

All the new development and updated amenities are adding more users to the already congested area which the proposed changes hope to alleviate (Amsterdam Zuidas, 2024). Part of the strategy to do so is to reallocate street space away from cars and add more greenspace to entice more pedestrians and cyclists (Amsterdam Zuidas, 2023). This desire to use some of the car space for other uses is what attracts the

dynamic roads idea. Dynamic roads could be a way to simultaneously add amenity value, while optimizing the street space used for transportation.

Map 1 (below) illustrates plans for the area which include conversion of two-way car streets into one ways, implementation of a car "superblock" around the main station area, reconfiguration of the tram and bus lines, and more pedestrian and cycle access in the area. It is evident that there is a desire for more people-centered street design in the area and a shift away from cars.



Map 1: Zuidas Update Plans. Source: Gemeente Amsterdam. (2023).

The projects' aim is to address the growing issue of space scarcity and accessibility problems by reallocating space away from cars (reducing parking spaces and altering the car right-of-way), and encouraging residents, workers, and students in the area to travel outside of peak hours to reduce congestion (Amsterdam Zuidas, 2023, 2024). These goals align with that of the dynamic roads, so this area has been identified by XCARCITY, a program experimenting with the idea, as a potential location for implementation of dynamic roads (XCARCITY, 2024). There is potential for dynamic space allocation here to accommodate the different demands for the area while balancing vehicular throughput with pedestrian comfort and managing peak hour congestion.

Before consideration of a dynamic road plan in the area can commence, evaluation of the capabilities of the surrounding vulnerable residents must take place to avoid their social isolation as a result of this smart mobility implementation.

5.3 Data Collection and Analysis Methods

5.3.1 Survey

Since capabilities are so individual, I have opted for a survey approach that asks individuals to describe their current travel patterns and technology use. From the results of the survey, assessments can be made of their current abilities when it comes to these topics, as well as modal preference. A survey method to capture the capabilities of a population has been used before by many researchers and academics, to understand the capabilities of a population prior to implementing new design so as to create something that is accessible to all (Tenneti et al., 2013; Djoub, 2013).

By understanding their capabilities and preferences, recommendations can be made for the protection of accessibility for this vulnerable elderly population, as changes to the transportation system around them are being proposed (Tenneti et al., 2013). In addition to questions about their transportation patterns, the survey will also ask questions to assess their capabilities around the use of smart technology to gain an understanding of their ability to receive route planning information in a technology format. To use dynamic roads, access to information in this way is important, and by understanding this aspect, choices can be made about both implementing dynamic roads, as well as potential education opportunities to get an older generation up to speed with the latest technology. This survey serves as the main source of data through which to analyze the equity implications of the proposed project.

Although some may have opted for interviews, there are several reasons why a more standard survey approach better suits my needs. Because I do not speak Dutch and am working with an older population whose mother tongue is Dutch, using a standardized survey is the best way to capture the experiences of the community as it is easily translated and can be administered with the help of a native Dutch speaker. The goal of the study is to capture the nature of the target population's travel behaviors and values which can more reliably be done with a broad survey. Uyan-Semerci (2007) notes that “users of the capability approach have to engage in a more dialogical process, sensitive to the claims of different peoples in order to enrich the perspective of this framework” (p. 204). In lieu of an in-depth interview process, surveys are the next best step to achieve this dialogue. Surveys done in-person, conducted by the researcher are best utilized for studies that gauge the attitudes and preferences of a group so that the researcher can make informed assumptions about the population (Richardson et al., 1995).

The goal of the survey is to gain an understanding of what the elderly residents’ current travel patterns and choices are, and what factors influence their ability to access different opportunities in the city. This will help me to determine what dynamic road space allocation would mean for their daily lives and to make recommendations for maintained and expanded accessibility. This falls into the third category of survey purposes described by Richardson et al. (1995), namely to predict the effects of system changes on a given population.

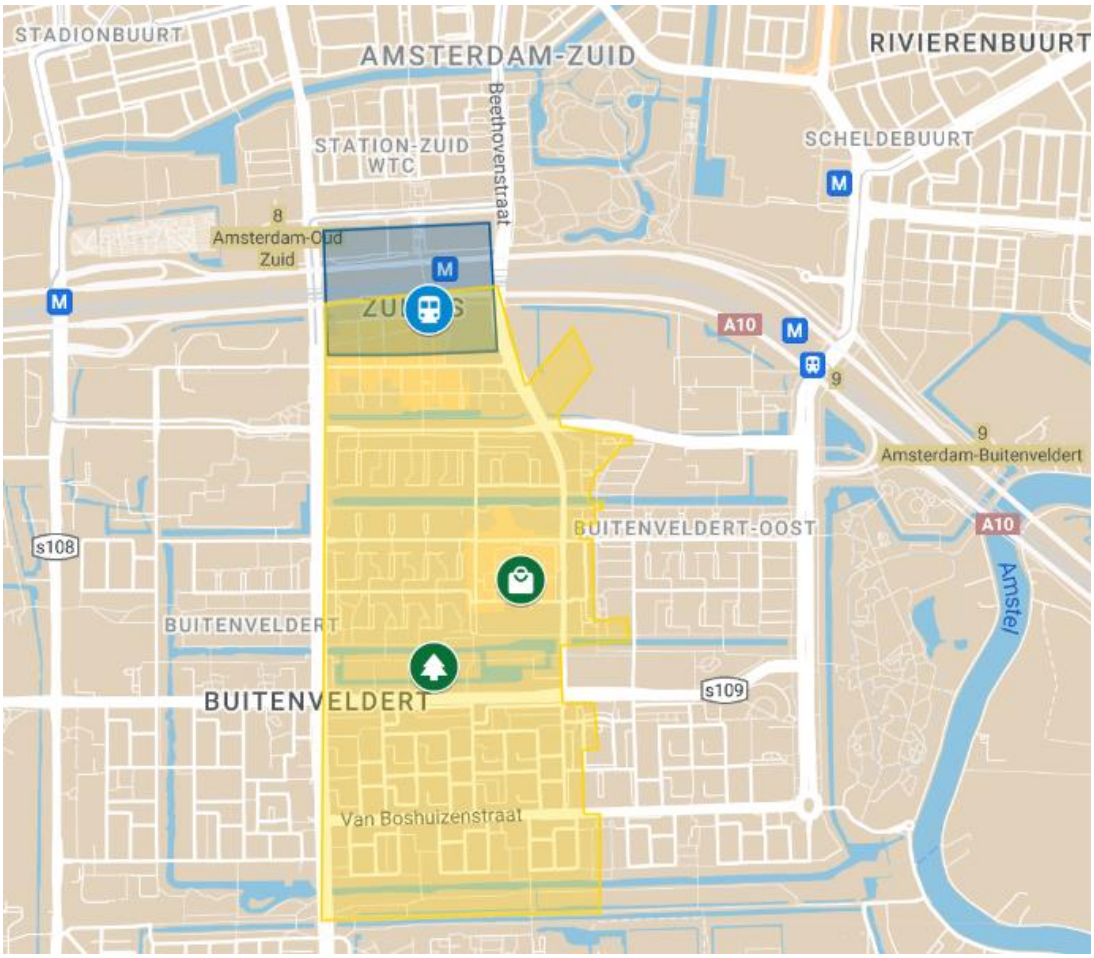
Survey Administration and Design

The survey is used to gain first-hand input from elderly residents about the capabilities they possess and use to access transportation options and subsequent opportunities in the city. Through use of a survey, elderly residents are involved in the planning process, proving insights about the infrastructures that can be used to enhance the lived accessibility of the transportation system. In most studies, the information to analyze the way people use the road comes mainly from internet applications, smartphones, and other devices, (Valença et al., 2021, p. 4). This leaves out information on those who might not use such tools, like older adults, low income, disabled, etc. This survey process, administered in person, will help to bridge

this gap, bringing in the voices of elderly users who might have been previously excluded due to technological limitation. A similar approach was used by Finkelstein et al. (2023) in their study of elder experiences with technology support services.

Target Group

The surveys were administered in the case study area of Buitenveldert in Amsterdam. The target group is residents of the area who are aged 65+. In order to get an accurate population number for the area surveyed, I conducted surveys in the 1082 postal code area of the Buitenveldert. The area is shown in yellow on Map 2. This section includes the core of the neighborhood and extends to the Zuid station area (indicated in blue). For the sake of readability, I will refer to this area as Buitenveldert. According to CBS, in 2023 there were about 1975 residents over the age of 65 out of 5555 total residents in this postal code (Centraal Bureau voor Statistiek, 2023c).



Map 2: Location of Survey Collection. Source: Author

Recruitment strategy

In order to capture a randomized sample of the target group, hubs of elder activity were identified such as Gijsbrecht van Aemstelpark and Gelderlandplein shopping center, where many different kinds of activities take place. These locations are indicated with green icons on Map 2 Using the intercept survey method (Richardson et al., 1995), I was able to capture data from residents while they were going about their daily lives. In-person surveys, where the researcher interviews respondents in real time, have higher

response rates than other forms of survey completion (such as telephone interviews, or mail-back surveys), as well as allow opportunity for the researcher to pick up on nuances within the answers (Richardson et al., 1995).

However, there are some challenges to this strategy as outlined by Richardson et al. (1995). By interrupting the daily lives of respondents, causing inconveniences, they may rush through the questions and not answer them to the best of their ability, generating inaccurate results. There can also be bias from the side of the survey administrator as well. They might communicate their opinions subconsciously in the way they ask questions and influence the answers provided by the respondent. Attempts were made to avoid these biases by reading a standard list of questions, as well as minimizing the time it takes to complete the survey.

The majority of the responses were collected in Dutch, the mother tongue of almost all of the population that resides in Buitenveldert. Responses were collected over seven days, at different times and different days of the week in order to minimize preference for those who are able to participate at certain times of day.

Sample Size

I collected 65 responses to grant a representative sample at 90% confidence of the total 1975 elderly residents of Buitenveldert. In order to get the highest quality of responses with the time and resource budget available for this project, a 90% confidence is the highest that can realistically be achieved. Determination of this sample size was calculated by using the Central Limit Theorem (Richardson et al. 1995). The theorem is then applied to the proportion of respondents who did NOT answer that they "always check the route before departure" in my 21-sample pilot study. This method is described by Richardson et al. (1995).

Utilizing this equation, the level of confidence must be defined first. In my case, I opt for a 90% confidence, or 10% standard error. The standard error is then divided by its respective z-score; in this case, 1.645. The remaining standard error for an estimation of a proportion p, is characterized as a percentage:

$$s.e.(p) = \frac{10}{1.645} = 6.0790 \text{ percentage points}$$

Then, the required sample size at the desired confidence level can be determined in a two-step calculation, using the data from the pilot case. First, I defined the sample size required for an infinite population (n'), using the proportion of those who did NOT answer that they "always check the route before departure" in the pilot study (52.38%), divided by the squared standard error.

$$n' = \frac{52.38 \times (1 - 52.38)}{6.0790^2} = 67.497$$

Next, the finite population correction factor is applied.

$$n = \frac{67.497}{1 + \frac{67.497}{1975}} = 65.27$$

The result indicates that 65 respondents should be surveyed to get a 90% accurate read on the capabilities and travel behaviors of the target population.

Question Design

The survey is designed to determine the different elements of Sen's capability approach, defined by Vecchio and Martens (2021). It includes questions to determine what resources, conversion factors, capabilities, and functionings this elderly population currently has access to. These come together to determine the overall "capabilities" of the elderly population as a whole. The main capabilities investigated is the use of smart devices, and travel behaviors. Anand et al. (2007) lays out the possibilities of different types of questions to use when a researcher is attempting to define an indicator of a capability through use of a survey:

> Questions about access to facilities, like the use of a car or van when needed, and questions about the existence of factors preventing people from moving house illustrate questions capable of generating type 1 and 2 indicators. In some cases, it is possible to use questions about functionings, when combined with reasons, to determine whether a particular behavior or state reflects a person's preference or inability to make certain choices. And in a smaller number of situations, functioning questions … can be assumed to indicate evidence of a reduced capability set. (p. 57).

I used a similar strategy to determine the capabilities of the target (elderly) population, sampling based on measurable indicators such as: Modal preference, temporal flexibility, access to smart devices and the ability to use them. Other studies suggest the use of a travel diary to determine travel patterns (Prelipcean et al., 2018), but as I am working with an elderly population, questions that require memory recall (such as asking for an exact account of recent trips) are limited so as not to overly burden potentially memory-challenged individuals.

After basic demographic questions covering age and retirement status, the questions fall into four categories, defined by Anand et al. (2007). First, externally oriented questions about opportunity such as, "how often do you engage in social activities, and what mode do you use to get there?". Second, explicit questions about personal ability aspects of a capability (conversion factor) such as, "can you use a smart device?". Third, explicit capability constraint questions like "if your main mode of travel were suddenly unavailable, would you still be able to reach your destinations?". And four, functioning probes combined with questions about reasons, for example, "what modes do you use for most trips, and what is your motivation for this choice?" The types of questions and examples of them are displayed in Table 1 (see full survey in Appendix A). With these types of questions, I can determine the resources, conversion factors, capabilities, and functionings of the population and relate them back to the capabilities required to utilize dynamic roads effectively.

Questions / Statements	Category
Do you own a smartphone or other smart device?	Resources
Can you use a smart device?	Capabilities
What do you use your smart device for? (select all that apply)	Capabilities
How often do you travel from Zuidas station?	Functionings
What modes do you use for most trips?	Capabilities
What is your motivation for your travel choice?	Conversion Factors
Would you still be able to reach your destinations without your preferred mode?	Conversion Factors
Do you check your route before you leave via smart device?	Capabilities
Do you usually travel around the same times of day?	Conversion Factors
If yes to the previous question, what time of day do you normally travel?	Conversion Factors
On average, how many times per week do you engage in social activities?	Wellbeing
What mode(s) do you use to get to social engagements?	Wellbeing
I am satisfied with the current mobility options available to me.	Wellbeing
I am confident in my ability to use smart technology (smartphone, tablet)	Wellbeing
I have a full and satisfying social life.	Wellbeing
Are there places you would like to be able to go in the city but feel you cannot get to?	Functionings
Which activies do you feel unable to reach?	Wellbeing
Please describe what limitations you face.	Capabilities

Table 1: Survey questions, categorized

Survey Data Analysis Method

I performed both qualitative and quantitative analysis to make assumptions about the total elderly population of Buitenveldert from the sample collected. Much of the analysis is quantitative in nature, deriving from closed and multiple-choice questions. Since the survey was administered in-person by the researcher, the respondents were able to elaborate on their answers and have short discussions on the topic of their mobility. This provided insights that can be analyzed in a qualitative discussion, investigating the nuances that these comments provide in addition to the raw data collected. The questions have mainly

to do with the resources, capabilities, and functionings of the sample population. Because the sample size (calculated above) is proportionate to the desired confidence level (90% confidence), it is possible to use the statistics collected to make a reasonable estimate about the remaining population (Chambers & Skinner, 2003).

The focus of this study is on how people of a more advanced age use the modes and technology available to them, and how changes to the current system of roads and access might affect their mobility and subsequent wellbeing. To determine the wellbeing of the surveyed community, I use their level of social interaction as an indicator. This method stems from the Brede-Welvaart program, which measures the "broad welfare" of the Dutch population, using a variety of different indicators to do so (Centraal bureau voor statistiek, 2022b). By studying nuanced indicators in tandem, it is possible to find relationships between the different themes and make decisions accordingly so as to positively impact the experienced welfare of residents in affected areas (Combé & Kwee, 2023). The goal of the Brede-Welvaart project is to have some indication of the impact of city policies and projects, prior to their implementation (Combé & Kwee, 2023). This same principle is applied to this research project, attempting to counteract negative equity implications of dynamic roads before their implementation. Brede-Welvaart offers a holistic approach to measuring wellbeing that takes into account ecological, spatial, and social indicators. This research project uses the principles of Brede-Welvaart to measure the potential equity impacts of proposed dynamic street implementation on elderly residents in Amsterdam in a nuanced way, focusing on the labor and leisure time, as well as the subjective wellbeing categories (Central bureau voor statistiek, 2022b). By measuring the capabilities of this vulnerable population in a holistic way, it becomes clearer whether proposed plans are in accordance with these discovered traits.

5.3.2 Document Search

For document search on issues of transportation, Richardson et al. (1995) recommends investigating documents which are recently updated, which contain relevant statistics and current plans on the topic of interest. Following this guidance, policies reviewed fall into the categories of transportation plans, sustainability plans, and equity goals of the city of Amsterdam. Specific policies analyzed were; The Voluntary Local Review from 2022 (City of Amsterdam, 2022), Toekomstvisie Sociaal Vervoer (Gemeente Amsterdam, 2021), and MaaS aan de Amstel (Gemeente Amsterdam, 2018). In addition to these city-wide documents, specific plans for the Zuid station were analyzed such as The Sustainably Accessible Zuidflank Mobility Plan (Gemeente Amsterdam, 2023), as well as official blogs on the update process and plans for the Zuidas area (Amsterdam Zuidas, 2023, 2024). For the documents that were only available in Dutch, I translated with Google Translate.

By reading through these plans, I assessed the level of consideration given to elderly access in the design. I then assessed if the plans for the update reflect the goals around equity and inclusion (defined by the city of Amsterdam). Using the results from the survey as a reference point, I was then able to determine if the capabilities described by the population themselves are compatible with the plans to achieve the accessibility and inclusion goals.

Document Search Analysis Method

I performed policy analysis using methods described by The Quebec National Collaborating Centre for Healthy Public Policy to understand if the policies outlined in the targeted documents align with municipal goals around equity and inclusion (National Collaborating Centre for Healthy Public Policy, 2012). Their analysis framework is designed to analyze the effects (both intended and potential unintended) on equity

of proposed changes. Through this analytical framework I will discuss if the proposed policies for the Zuidas area align with the capabilities of the neighboring elderly community in order to reach Amsterdam's goals of equity and inclusion.

Results and Analysis

This section is structured as follows: First, the results of the survey are discussed, defining the capabilities that the elderly population of Buitenveldert possesses. This discussion includes an investigation of the compatibility of the resources, conversion factors, capabilities, and functionings with dynamic roads, towards achieving greater than current levels of wellbeing for the elderly population of Buitenveldert. Then, the results of the document search define the goals for accessibility for Amsterdam and highlight the plans for the Amsterdam Zuid station update, as indicated in Figure 3. The section wraps up with a discussion of whether the plans, including implementation of dynamic roads, will achieve these goals, bearing in mind the capabilities of the elderly population discovered in the survey.

The capabilities defined, and the goals articulated, form concurrent lenses through which to analyze the proposed changes to the Zuid station, including dynamic roads. In order to achieve the accessibility goals for the area, the infrastructures included in the update must match the capabilities of the population. This analysis will determine if the capabilities of the elderly population, defined by the survey, align with the capabilities required to use dynamic roads, in order to adhere to the accessibility goals of the city.

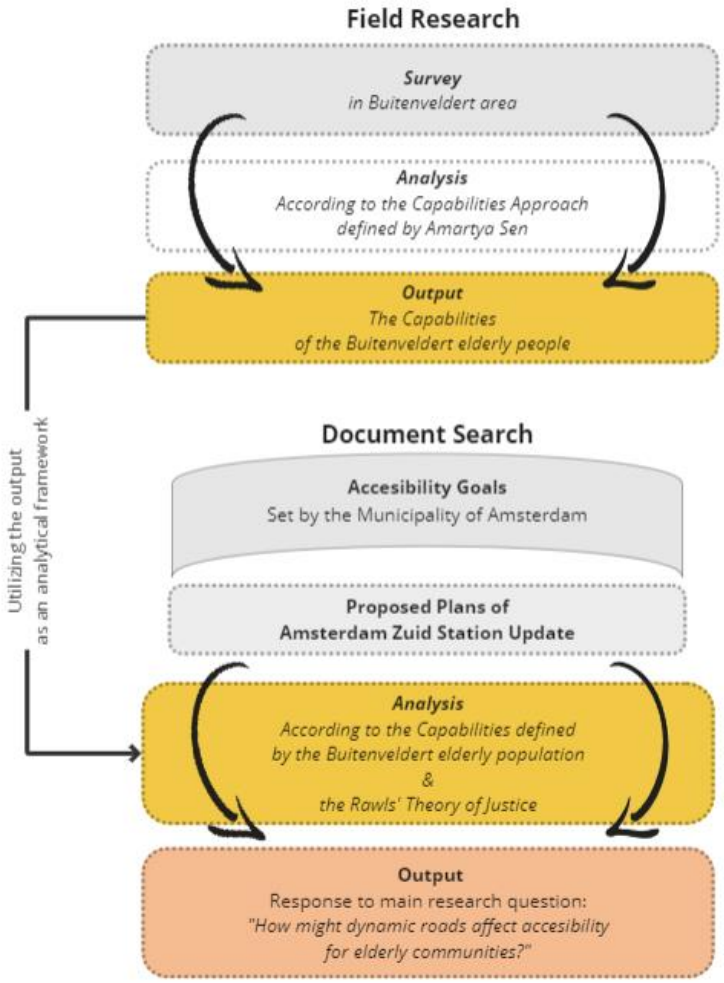


Figure 3: Diagram of Process. Source: Author

6.1 Results from the survey

The results from the survey reveal trends in the resources, conversion factors, capabilities, functionings, and wellbeing (as a group, referred to as “capabilities”) in the elderly population related to their travel behaviors and technological capacities. This section aims to answer the research sub question: What lifestyle factors of the elderly population dictate their access to opportunities via transportation? Specifically, looking at the time sensitivities of elderly populations, as well as technological ability in order to determine how implementation of dynamic streets might affect their ability to move in Amsterdam.

Resources

Access to Smart Device

With the implementation of dynamic roads, access to a smart device is increasingly becoming vital for the ability to predict a route. With the addition of a dynamic variation element to roads, users without access to a smart device face the risk of significant delays to their trip if roads that they expect to be available are not. This can lead to a more limited feeling of accessibility for the user, as well as increased road congestion if travelers are taking longer to get from A to B.

When asked if they own a smart device, 86% of the respondents indicated that they do. Those that reported no, usually indicated that they lived with someone who had access to such a device. Access to smart devices does seem to not be an issue. The ability to use a smart device effectively seems to be more of a concern. Most elderly users report being able to use a smart device, but mainly for communication purposes, not for accessing the internet or other applications. This is discussed further in the "capabilities" section.

Conversion factors

Route checking

Dynamic roads by nature are varying and somewhat unpredictable (Valença et al., 2021). This means that when traveling, mobility users will have a high chance of encountering a change in their expected path. For younger generations, a simple way to remedy this unpredictability would be to check their route before they leave via a smart device. However, when asked, only about 17% of elderly people reported always using a smart device to check their route conditions before they leave. An additional 26% of respondents reported sometimes checking their route, leaving 54% of respondents reporting that they never check their route before departure. About 3% of those surveyed reported using other sources to check their routes, such as asking family members, who do so using a smart device. As these results indicate, and as Figure 4 shows, the majority of elderly residents do not check their route before traveling. Not knowing which route to take to access amenities and opportunities creates a barrier to accessibility, and risks limiting the mobility of this vulnerable population. This makes it challenging for dynamic roads to present an inclusive mobility solution for elderly populations.

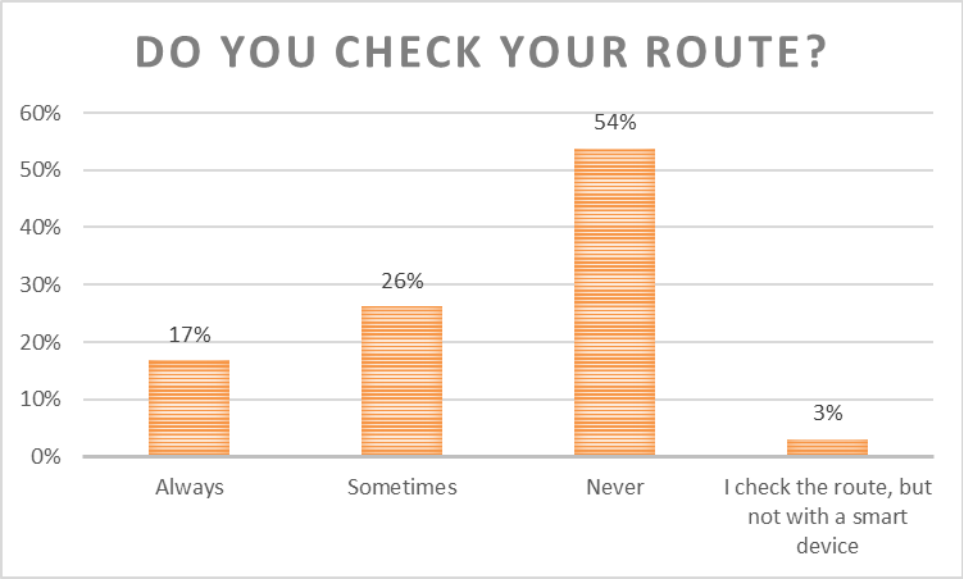


Figure 4: Frequency of route checking. Source: Author

Schedule Flexibility

As shown in Figure 5, about 66% of respondents reported having a flexible schedule, meaning that they do not travel around the same times of day, generally. An additional 17% of respondents say their flexibility depends on certain factors that arise with some regularity, so they also fall into a flexible schedule category, adding up to a total of about 83% of respondents with a flexible schedule.

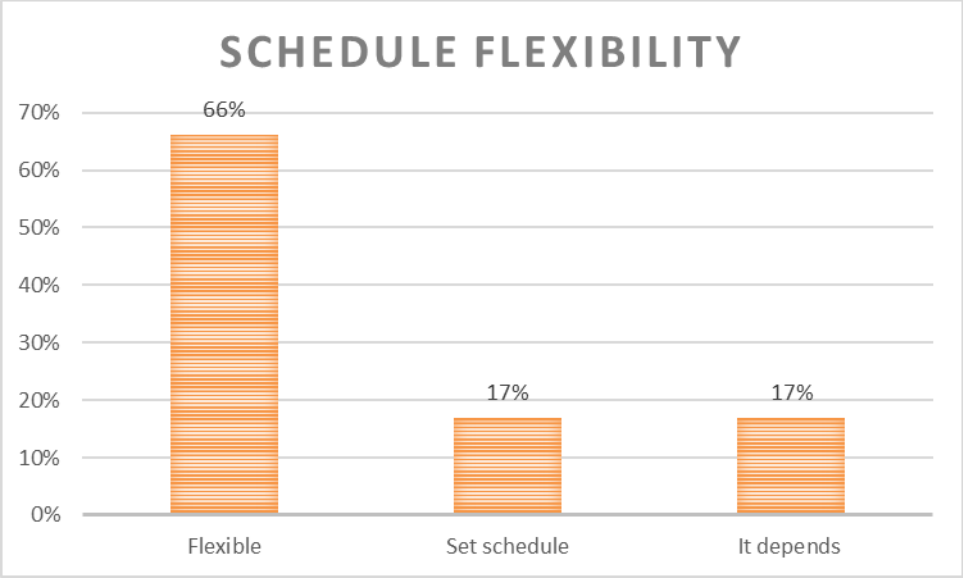


Figure 5: Level of schedule flexibility. Source: Author

Schedule flexibility has the potential to be either problematic or advantageous, depending on if users also use route-checking strategies before they leave. If a person checks their route before they leave, it is an asset because they can plan their trip around road changes, potentially changing the time they leave in

order to take their preferred mode. For example, if they wish to drive to a destination and check their route before they leave, they might see that the road they want to use is temporarily unavailable and choose to leave at a different time. If a person does not check their route prior to leaving, temporal flexibility means that users will not be able to predict what a route may look like if it is being dynamically altered, both with their own variance, and with the variance of the road. So even if the dynamic roads follow a pattern (which may not be the case), the variability of one's own personal schedule may interfere with the usability of the road.

Those who both do not check their route, and have a flexible schedule have the least conversion factors to make dynamic roads useful to them. As Figure 6, 42% of the sampled individuals travel at varying times, and never check their route. This results in close to half of the population being negatively impacted by a dynamic road system.

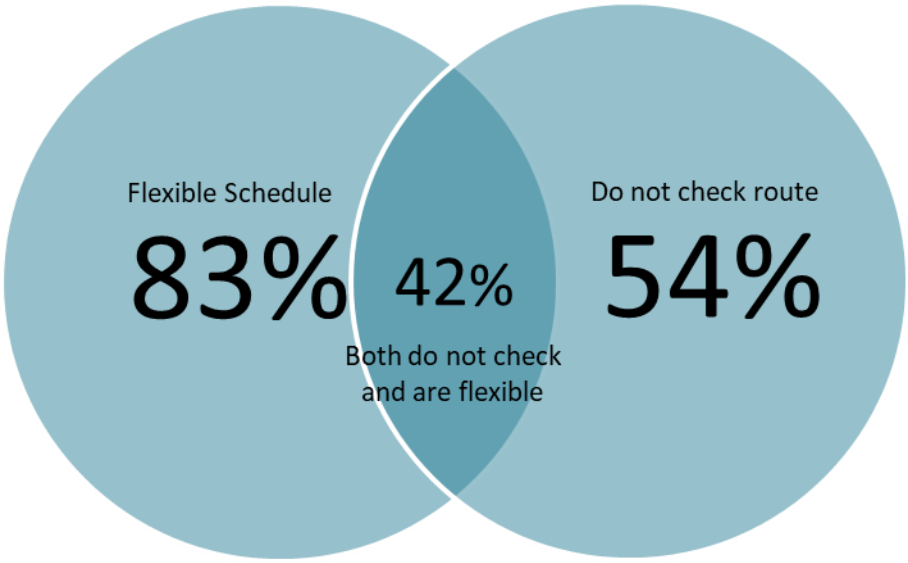


Figure 6: Percentage of most vulnerable. Source: Author

Capabilities

Ability to use a smart device

Only about 17% of elderly people surveyed reported that they cannot use a smart device, leaving the remaining 83% of respondents seemingly confident in their technological prowess. This is a good sign for the above-mentioned reasons in ability to check their route in the event of dynamic road implementation, however, when asked what they use their smart device for, results were less promising. Figure 7 shows that only about 56% of respondents reported using their smart device for navigation purposes (such as google maps), and only 14% of respondents said that they use their smart device for route scheduling applications to check on train or bus routes. These results indicate that while they may not be in the habit of checking their travel routes, there is the possibility of learning this skill and implementing the habit, if necessary, in the future.

One of the indicators of a quality transportation system is the predictability of it. Generally speaking, when users do not feel the need to plan and schedule their trip around the schedule of the transportation network, this means that the frequency and reliability of the system is great. The finding that about half

of the target population never checks their route should be a good thing, however, dynamic roads introduce an element of unreliability that changes this narrative, forcing users to take into consideration the suddenly more unpredictable roads network. This reinstates an accessibility bias that favors the technologically literate, which elderly populations tend not to be (Finkelstein et al., 2023).

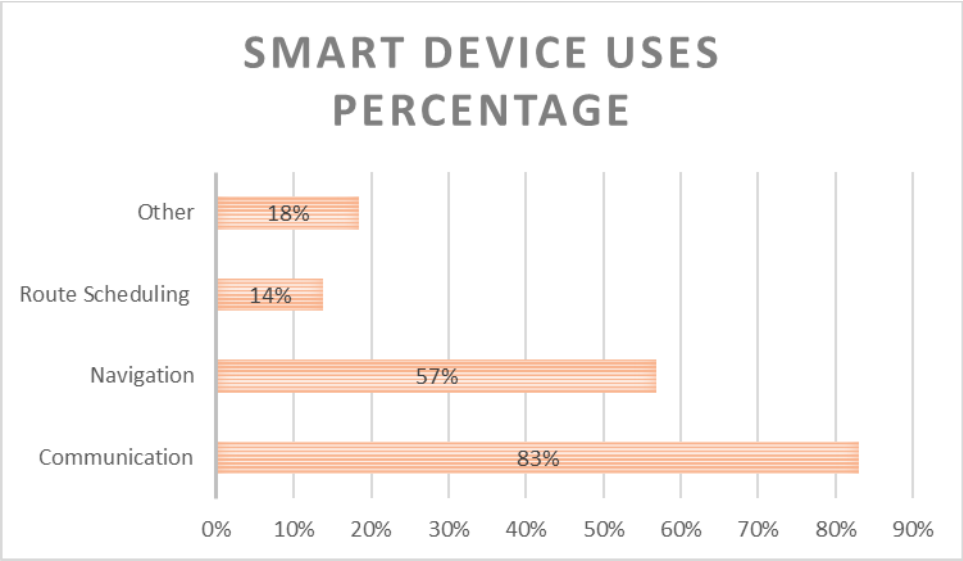


Figure 7: Reasons for smart device use. Source: Author

Preferred modes

As shown in Figure 8, the most common modes of travel for the sampled group were driving (a car), taking public transportation, and walking. Respondents could select multiple options to indicate their most frequented modes, so the numbers show the percentage of the time each option was selected. Most respondents shared that they prefer the car for most trips due to the physical limitations that come with advancing age, but noted that they prefer to use public transportation when they go into the city center (of Amsterdam) because of a lack of parking options.

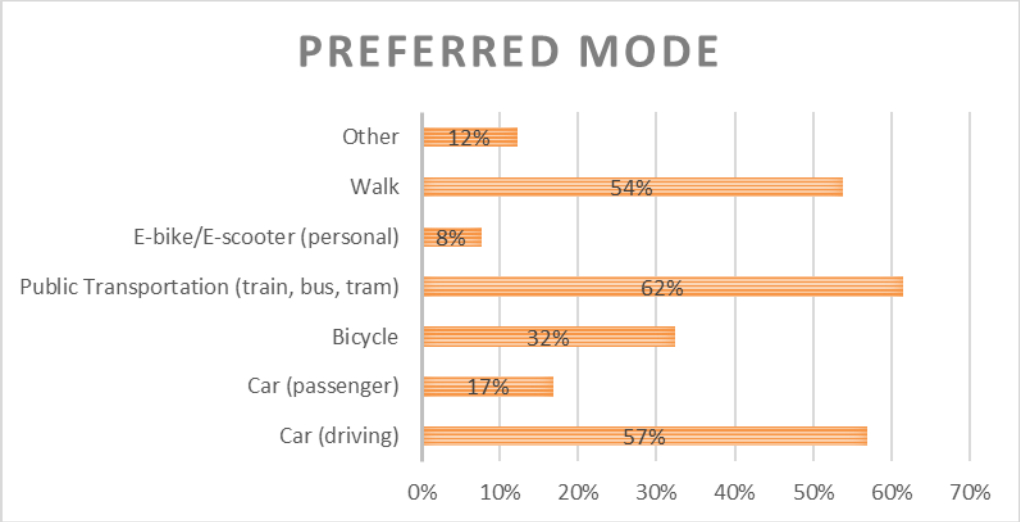


Figure 8: Preferred modes of elderly residents. Source: Author

Figure 9 shows that the main considerations for mode choice were overall convenience, speed, and comfort. There was little cited consideration for other reasons such as safety, monetary cost, enjoyment, or environmental concern. When asked what they would do if their first choice of mode were unavailable, a vast majority said that they would simply call a taxi, and this would solve their problem. This indicates that, especially in an older community, cars are still a highly valued and relied-upon mode of transportation.

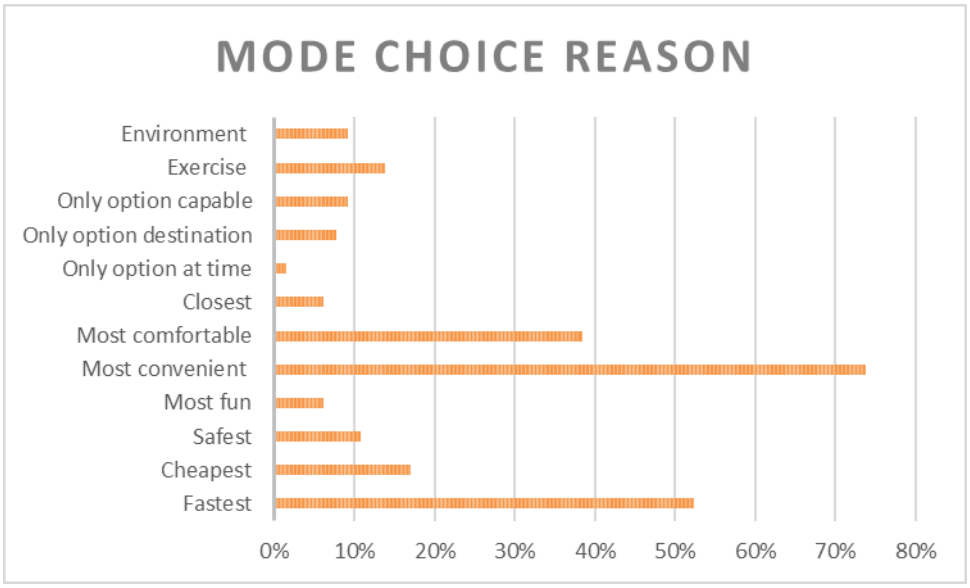


Figure 9: Reason for choosing mode. Source: Author

The plans for the Zuidas area are focused on reducing car use, as are the goals of dynamic roads. Since this population is so reliant on the car as a means of travel, implementing these plans could result in a lowered level of accessibility for elderly people if other accommodation isn't made available.

Functionings

Use of the Zuid Station

More than half of those surveyed reported almost never traveling from the Amsterdam Zuid station. The breakdown of Zuid station use by residents is shown in Figure 10. Upon further discussion, it was discovered that most choose to use the nearby tram stop for their public transport needs, using it to get anywhere that is not in the immediate neighborhood (such as the city center). It is unclear if changes to the accessibility of the Zuid station would result in changes in user behavior, but it likely would not, as residents report being satisfied with the amenities around them (green space, shopping, transportation options). Proposed changes to the station which include additional public gathering space, and greenspace may not entice them to change their behavior.

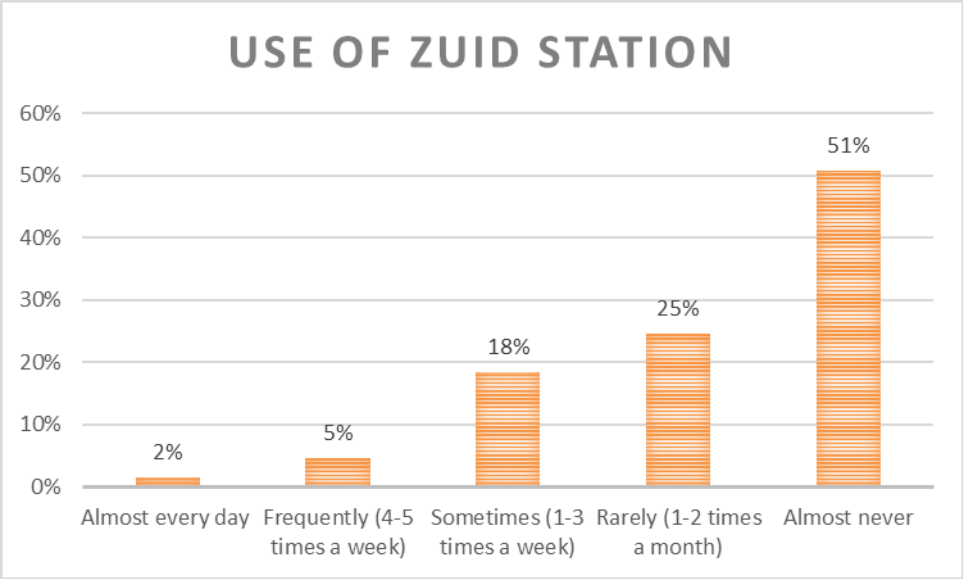


Figure 9: Frequency of use of Zuid station. Source: Author

Ability to Travel without Preferred Mode

When asked if they would be able to reach their desired destinations if their ability to use their stated preferred mode, less than half reported that yes, they would be able to reach all destinations (40%), with the second largest category being yes, they could reach most destinations (36%). The most common reason being that they would simply be able to call a taxi if they found they could not move independently with their own vehicle, or with public transportation.

Wellbeing

Social engagement

Social activities are harder to come by for the older population and are a good indicator of overall wellbeing for this group. A vast majority of those questioned indicated that they feel their social life is full and satisfying, indicating that the current transportation options and systems are satisfactory to maintain an adequate level of wellbeing (in this regard). Figure 10 shows that almost half of respondents engage in

social activities with friends or family two or three times per week. 22% reported having social activities five or more times per week, and 19% reported once or less than once per week. Most walk (40%), drive (49%), or use public transportation (42%) to get to their social engagements. Since walking, driving, and taking public transportation are the most popular modes that the elderly population uses, these are the modes that require the most attention for the wellbeing of the elderly community. It is important to maintain these modes so that changes to the system do not reduce their access to social interaction and subsequent wellbeing.

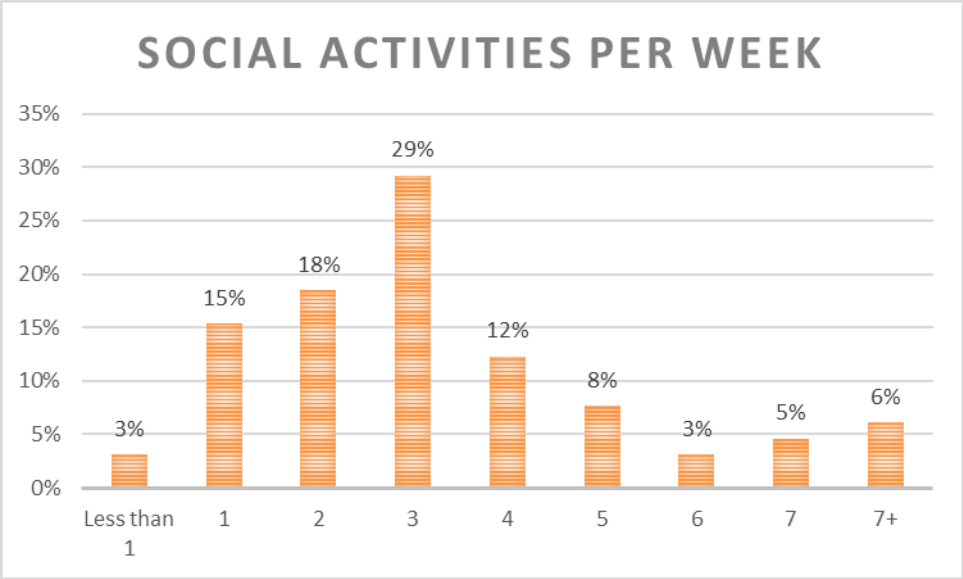


Figure 10: Level of social interaction. Source: Author

Capabilities Summarized

To answer the question, “what lifestyle factors of the elderly population dictate their access to opportunities via transportation”, the results of the survey, defining the capabilities of the elderly population in regard to transportation are summarized in Table 2:

Resources	Conversion factors	Capabilities	Functionings
Most have access to a smart device	Most do not check their route prior to leaving	Comfortable using a smart device	Most never go to the Zuid station– preferring instead to use a nearby tram stop
	Most have flexible schedules (travel at varying times)	Most use car or public transportation to move	If there were a problem with their first choice of mode, most reported that they would simply call a taxi
		The reason for their mode choice is simply that it is the most convenient	Most are satisfied with the amenities available via mode of choice

Table 2: Summary of Capabilities

The elderly Buitenveldert population has access to smart devices, but mainly use them for communication. This indicates that they may be able to learn to use their devices for route planning, but that they are not currently using them in this way. Additionally, as most are retired, elderly people are not bound to a typical daily commute, which grants them flexibility in their travel patterns. They move using a car or public transportation mainly, due it its proximity and convenience. If unable to use these modes for some reason, most would choose to call a taxi as their alternative option. Finally, most never go to the Amsterdam Zuid station, opting instead for a closer tram or bus stop, if using public transport.

Most residents surveyed indicated that they are satisfied with the level of accessibility they have now, so any changes to be made would have to meet or increase the levels of access they currently experience. However, the results indicate that the implementation of dynamic roads would not increase the access to amenities and opportunities for the population of elderly residents living in this area, instead it has the potential to reduce their access. This is because the capabilities required to access the necessary information for dynamic roads are not currently within the scope of capabilities that the population possesses.

The capabilities of the elderly population of Buitenveldert, defined here, are used as the reference point to assess accessibility of dynamic roads as part of the Zuid station update.

6.2 Document Search Results

This section aims to answer the research sub question: Does the implementation of dynamic roads align with Amsterdam's equity and access goals? To do this I will use the analytical framework discussed above for analyzing equity and inclusion (National Collaborating Centre for Healthy Public Policy, 2012). Specifically, I will provide a background on what the goals are for the city and what specific infrastructure changes are proposed to meet these goals.

This section will provide a definition of what Amsterdam's goals are as a city when it comes to equity and access, followed by an analysis of if the Zuidas update plans are compatible with dynamic roads, and if the updates and potential dynamic elements are compatible with these goals.

Amsterdam Goals:

The Netherlands uses the United Nations sustainable development goals (UNSDG) to strategize their own sustainability goals. The UNSDGs consist of many sections, but the one that is most relevant to this thesis is sustainable development goal 11: Sustainable cities and communities. Within this goal is a subgoal of access to sustainable transport (United Nations, 2024). The following sections describe the specific goals the Amsterdam municipality has taken on in order to achieve this greater end.

Access to Sustainable Transport

In the voluntary local review (City of Amsterdam, 2022), the city of Amsterdam lays out a goal to "provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons" (p. 89) by the year 2030. In this goal they specifically mention older persons, drawing attention to the fact that these people have different requirements and capabilities than the general population. However, in this same document, they noted that Amsterdam is less accessible via bicycle to vulnerable groups like the elderly, when compared to other Dutch municipalities (City of Amsterdam, 2022). While around the world, Amsterdam is often viewed as an accessibility haven (in terms of transportation), there is still much room for growth in their accessibility levels.

In the Toekomstvisie Sociaal Vervoe, which defines the future inclusive transportation measures in the city of Amsterdam, the municipality introduced a policy framework for inclusive mobility (Gemeente Amsterdam, 2021). This framework sets out the goal that all citizens should be able to participate fully in civil society, regardless of disability (mental or physical). While not exclusive to elderly people, a large number of elderly people also fall into the category of disabled. An interesting point that the Toekomstvisie Sociaal Vervoe (Gemeente Amsterdam, 2021) highlights is that ensuring social transport options should not hinder the ambitions for sustainability and technological innovation. This means that we should not discount certain technologies because some people cannot use them, rather to find a way to integrate these users into an innovative system so that it works for them as well.

Remove Mental and Physical Barriers to Public Transport Use

One of the main points that this inclusive mobility document brings up is that making mobility inclusive means removing physical and mental barriers to the use of public transport (Gemeente Amsterdam, 2021). Physical barriers are often addressed in public transport design, but mental barriers are not so often tackled, especially when it comes to limitations that people have with technology. It then becomes a

question of balancing the two goals; not hindering advancement in the name of inclusion, while also not excluding users due to limited capabilities.

Gemeente Amsterdam has stated that an inclusive transit system is designed for everyone to be able to use. They state that digital space is also public space and should be treated as such, with accommodations for those with impairments (Gemeente Amsterdam, 2018). Currently, there are public transport coaches available to assist in learning how to use the various public transportation options available in Amsterdam, in an effort to reduce the mental burden of learning how to use the transportation systems (Gemeente Amsterdam, 2021). In terms of learning complimentary technology that may be required for dynamic road implementation, there are no stated resources available. This goes against the goal of providing information regarding travel planning, reservations, and payment in a way that is accessible to all travelers, regardless of disability (Gemeente Amsterdam, 2018). Since there are no current measures in place to ensure the accessibility of systems that do not yet require a smart device to access, it is unclear how dynamic roads would be able to function equitably (as they require some smart device access to understand the route restrictions at different moments).

Zuidas Update Plans:

Increased crowding in the Zuidas area due to recent development has brought attention to the fact that cars and their associated infrastructure take up a lot of space. The noise and congestion generated by cars creates a space that is not pleasant enough for leisure activities, and is inefficient to move through. Planners are tasked with reducing these negative impacts from cars, without reducing the accessibility of the area.

The general goal as stated in the sustainable, accessible mobility plan for the Zuidas area is to make Zuidas a pleasant place for visitors and residents both travel through, as well as relax and engage in leisure activities in (Gemeente Amsterdam, 2023). Despite this being the stated goal, much of the focus of the plan is on changing travel behaviors for commuters, rather than creating spaces for the local community.

One strategy planners and designers are focusing on is restructuring the transportation network in the area. This means a “focus on more space for walking, cycling, public transport and leisure and reduced car use, increased avoidance of peak periods and the spreading of car and public transport use” (Amsterdam Zuidas, 2024, p. 1). They want to both encourage more people to use modes other than a car, as well as to travel at off-peak times. In order to achieve this, they must expand the transit, cycling, and pedestrian network, while limiting the car network. The official plans for the Zuidas update do not include any reference to dynamic roads. However, it can be argued that the goals defined in these documents, namely, reducing space for cars in favor of space for other modes and uses, can be achieved by using dynamic roads as a tool to restructure street space.

The strategies for achieving this are broken up by mode in the Zuidflank Sustainable Mobility Plan (Gemeente Amsterdam, 2023). The categories are bicycles, pedestrians, public transportation, and cars. This analysis will focus on the modes identified in the survey that elderly residents of Buitenveldert use the most, namely walking, taking public transportation, and driving cars. Explored in the following is the mode-specific proposed changes, and then the potential for the specific actions outlined in the plan to incorporate dynamic elements, and finally the effects this may have on the accessibility of elder residents of nearby Buitenveldert.

Zuidas Goals: Pedestrians

Enhance Safety and Encourage Staying

In addition to changes made to the car infrastructure, there are other adjustments to be made in order to improve pedestrian safety and the overall experience in the area. There is emphasis on creating a space where people not only walk, but also stay in the area—essentially making the Zuidas area not only a node for transportation as it is currently, but also a destination in itself (Gemeente Amsterdam, 2023; Amsterdam Zuidas, 2023). This could include the incorporation of more greenspace in public areas, as well as benches for relaxation. The results of the survey show that over half of respondents almost never go to the Zuid station, but there is a possibility, that improved conditions for walking and staying in the area could entice more elderly residents of Buitenveldert to go to the area.

Zuidas Goals: Public Transportation

Greater Capacity

The general goal for public transportation is to provide more capacity for moving people to and from the Zuidas area. The current bus and tram lines and frequencies are not enough, and with the plans to disincentives use of the car, public transportation needs to be a viable option for more people (Gemeente Amsterdam, 2023). In accordance with this goal, the plans include measures to maintain transit lines during the major construction period, implementing temporary terminus for the tram line 52 at the Zuid station. This line is vital for the residents of Buitenveldert. Almost all residents indicated that they use this line to get to and from Amsterdam's city center, so maintenance of this line is necessary.

Most of the plans laid out in the Zuidflank Sustainable Mobility Plan involve the expansion of stations to accommodate more user throughput. This is an admirable goal, but only takes into account commuter passengers rather than the needs of those who live in the community. The focus on expansion for nine-to-five commuters neglects the needs of the 24/7 residents.

Zuidas Goals: Cars

Reduce Through-Traffic

One of the main changes that will take place is the creation of a "superblock" around the main station and pavilions. The superblock is a one-way circuit for cars that flows counter-clockwise, which limits right turns and forces cars to travel more slowly. Since it is a circuit, it is only useful for local trips, so this will limit the through-traffic in the heart of the Zuidas area. A reduction in through-traffic will limit noise and enhance safety for those in the vicinity.

Reduce Parking

A second major measure is the reduction of parking options. New developments in the area are encouraged to build with no or few parking spaces included in their designs. This is with the caveat that they will still include some options for visitors or people with disabilities. By reducing the number of available parking spaces, there is a disincentive to get to the area via car. Many of the surveyed residents of Buitenveldert reported that one of the major reasons that they do not drive into the center of Amsterdam is because parking is costly and difficult to find. With the implementation of a lower parking supply, the Zuidas area could cultivate this mentality around driving as well.

Reduce Speeds

There are several areas that are identified as reduced speed areas in the plans. These stretches of road are being converted from 50 km/h zones to 30 km/h zones. A few of these roads (Amstelveenseweg,

Buitenveldertselaan, and Van Leijenberghlaan) are major arteries that serve the Buitenveldert neighborhood. The goal is to improve safety and reduce noise pollution in these areas with this measure (Gemeente Amsterdam, 2023). An unintended consequence could be that it increases congestion, as these roads are main feeders to the Zuid station, and to the greater Amsterdam area beyond. While slower speeds will make pedestrians and cyclists safer in this area, it could reduce accessibility by car. As seen in the survey results, elderly residents in the Buitenveldert neighborhood are extremely car dependent, and this measure could impact their accessibility (both perceived and realized) to these areas.

Potential for Dynamic Road Implementation

In order for dynamic roads to fulfil the needs of the community in this area, there must be alignment both with the infrastructure goals in the Zuidas plans, as well as with the equity goals described by the city. A dynamic road might fit well with the specific infrastructure goals that the plans lay out, such as reducing car parking options, or expanding pedestrian infrastructure, but attention must be paid to if a dynamic element added to these solutions will challenge the equity goals that the city has committed to. These potential alignments and challenges are explored and analyzed in the following sections.

Pedestrians

The potential for dynamic road implementation here could be a bit more dramatic than for other modes. Since pedestrians are the most vulnerable group on the street, when making unexpected changes to accommodate them, more precautions must be taken. Dynamic pedestrian space could look like the conversion of a car lane to walking/public park space during off-peak hours. Using instruments like retractable bollards, or permeable pavement surfaces, it could be possible to create a pleasant space to be without fear of car infiltration. It is also possible to use parking spaces for the same uses. A parking space, when not in demand, can be converted into a parklet for either public or private (restaurant, cafe) use (City of San Francisco, 2020).

However, this approach has certain equity risks for elderly drivers. Unused to such road changes, they could pose a hazard to an older group of drivers, or cause unexpected delays to their trip. As shown from the survey, almost half of the respondents do not use smart devices for navigation, and even less use it for route scheduling. Via a smart device is often the easiest way to verify that a route will get a traveler from A to B, especially in the event of dynamic changes. Older populations usually feel very comfortable and familiar with their surroundings and the routes they use to get around. As a result, only 17% of the sampled elderly participants report always checking their route before they leave. With the implementation of unpredictable dynamic roads, they may have to change their behaviors to include regular route checking.

Public Transportation

For public transportation, the potential for dynamic road implementation has two phases. For the first, the temporary bus stops during construction lends itself well to the possibility of a dynamic element in the future. Although maybe not as feasible for a tram route which is by nature bound to the track lines, temporary bus stops based on user demand could serve a function in the area. Think, for example, of a bus line that can be redirected to an impermanent stop during off-peak times to pick up less mobile residents from a place close to their place of residence. This could serve as a hybrid between the more costly supplementary public transit that is offered for this kind of situation.

In the second phase, there is the potential for dynamic bus lanes in order to facilitate transit flow, especially during peak rush hours. Additionally, because there is a goal of reducing the speed of cars in the

area, by having a dynamic bus lane, buses would not be subjected to these lower speeds. While cars are stuck in slow-moving traffic, buses could continue with a bus lane that emerges on demand. This would work similarly to how emergency vehicles demand right of way. When a bus needs the lane, cars will have to yield the space for the bus to pass. This would help to achieve the goal of greater capacity as higher speeds mean more frequency at stops.

Cars

The reduction of parking capacity is highly compatible with dynamic roads. For example, there is the possibility of only having parking spots available for those who require it in the moment. This means that when no one requires the parking spots, they can be used for other purposes on the street, and only be made available upon demand. In this way, the spatial impact from the parking spot is reduced, without limiting the accessibility to the area.

Dynamic Road Alignment with Equity Goals

Although dynamic roads align well with the update plans for the Zuidas area, they do not align with the equity goals that the city of Amsterdam hopes to achieve. Based on the capabilities of the elderly population, determined by the survey, my results show that the implementation of dynamic roads would disproportionately negatively this vulnerable user group. Therefore, implementation of dynamic roads in their current conceptualization does not align with the city of Amsterdam's equity and accessibility goals.

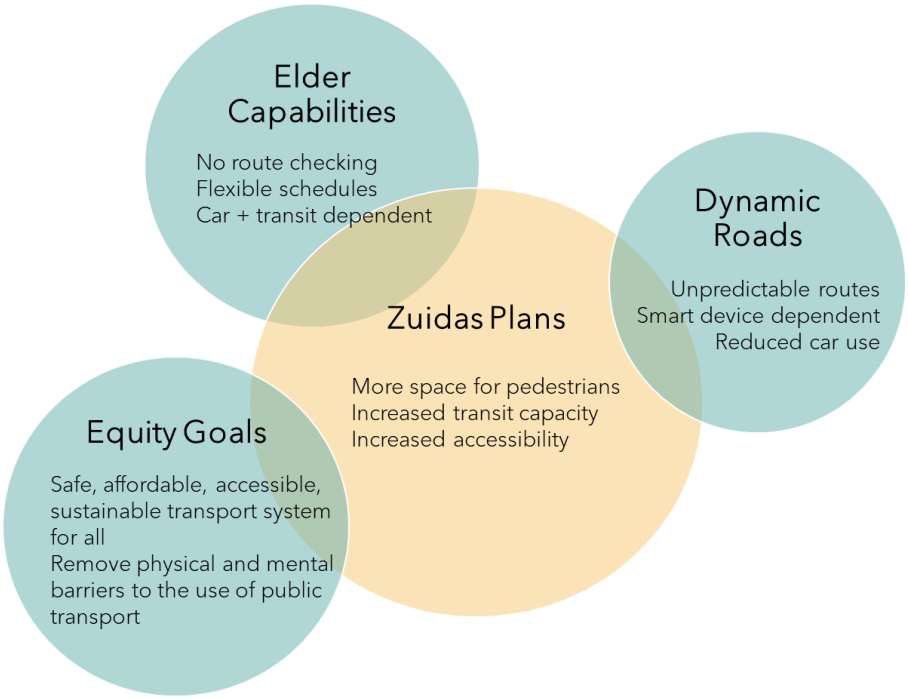


Figure 11: Alignments Illustrated. Source: Author

Figure 11 illustrates how although the Zuidas plans align with all three factors individually; the equity goals, elder capabilities, and dynamic roads, the three factors do not align with one another. In order for dynamic road implementation to be an equitable transportation solution, this alignment must be achieved.

The main issue inhibiting alignment between the three is the potential unpredictability of dynamic roads. As the results of the analysis show, elderly residents have highly flexible schedules, unbound by a workday commute, they travel at different times of day. This is possible due in large part to the reliability of the current road and transportation system in place. Namely, a static, and predictable one, which allows them to adopt an irregular travel schedule. These static roads have worked well for almost all of human existence, allowing all users to move at the time that works best for their needs and desires. However, as our cities get more crowded and streets become more congested, a need has arisen to optimize the way our transportation system works to combat this congestion. Dynamic roads hope to be the solution to this problem, matching their designs to the needs at a given time for the largest group of users. However, this utilitarian approach focuses on a workday commute schedule, and on alleviating the congestion that comes with it. This focus disregards the needs of a population who no longer travels on a static schedule, in the case of this study, elderly users, the large majority of whom are retired.

Planners risk subjecting populations who are left out of consideration for projects like this, to a post-apocalyptic scenario in which human movement is dictated by the patterns of the roads, not the other way around. If dynamic roads were to be implemented with the intent to alleviate workday-commute congestion, then those without the workday would either be forced to travel during these times, negating any progress made by these redesigns, or be forced to travel in ways and at times that are not optimal for them. Neither of these outcomes would be in line with the equity goals of Amsterdam, nor would they align with the goals of dynamic road space allocation—specifically to optimize the road use and travel behavior in a city-wide context. Vulnerable groups, and the elderly in particular are often left out of conversations regarding the planning of the urban environment, resulting in projects that are not compatible with their needs.

The inequality caused by unpredictability is compounded by the method used to dispense information about changing routes. As it currently stands, dispersing information via applications for smart devices is the most popular method, as it is the most convenient for spreading real-time updates about road conditions. However, as most elderly people are not regularly using smart devices to check route information, and have limited capabilities to use newer technology like smart phones and other smart devices, it is not an equitable way to inform the public about road changes. As discussed previously, Rawls' difference principle stipulates that social and economic inequalities should be arranged to grant advantage to the most disadvantaged groups (Rawls, 1999). In the case of dynamic roads and the resulting information dispersal, that means catering the way information is distributed to the capabilities of the least advantaged population, in my research case, elderly residents. Thus, implementation of dynamic roads that rely primarily on access to smart devices to obtain route information can negatively affect elderly people's accessibility to previously accessible amenities.

Using social activities as an indicator for wellbeing, the results of the survey show that most elderly residents of the Buitenveldert neighborhood are satisfied with their wellbeing levels. They use their preferred modes to get to and from social engagements and do not face significant infrastructure-related barriers for doing so. The implementation of dynamic roads in this area without catering to the capabilities

of the elderly population has the potential to jeopardize these wellbeing levels, introducing new hurdles to seeing family and friends.

Varying travel times compounded by varying roads, leads to high unpredictability. This unpredictability plus a lack of information equals inaccessible road infrastructure and a decreased level of wellbeing. This is the reality that elderly citizens will face with the potential implementation of dynamic roads. In order to stop this from happening, recommendations are given in the next section which hope to satisfy the needs of the community, while still allowing for the advancement of a dynamic road strategy.

Conclusion

7.1 Responding the Research Question

This thesis set out to answer the following question: **How might dynamic roads affect accessibility for elderly communities?** Through the development and use of a survey, the study determined what lifestyle factors of an elderly population dictate their access to opportunities via transportation. These lifestyle factors translated into the "capabilities" of the sampled elderly population. The indicated capabilities were then used to analyze whether the implementation of dynamic roads in the Zuidas area would result in an accessible transportation system for these elderly road users. The lens for accessibility was defined through Rawls' theory of Distributive Justice (1999). Next, in exploring various policy documents for the city of Amsterdam, the equity aspirations for the area were defined and used as an analytical framework for evaluating the potential inclusion of dynamic roads in the Zuidas area updates, with respect to the capabilities identified from the survey.

From the analysis it was determined that the inclusion of dynamic roads in the Zuidas update plans would have negative effects on the accessibility and subsequent wellbeing levels of the elderly population of the Buitenveldert neighborhood. The levels of accessibility currently in the area are adequate for the elderly population, who are able to have satisfactory social experiences using the current transportation networks. Therefore, any changes made to the transportation in the area should not decrease the accessibility levels. For the transportation systems to be in accordance with Rawls' Difference Principle (Rawls, 1999), the capabilities required to use the roads system, whether it be dynamic or not, must be aligned with the capabilities that the vulnerable, elderly community possess. Dynamic roads require some level of pre-departure route check with a smart device, due to their inherent unpredictability. As determined with the sample group, most elderly people do not have the capabilities to pre check the route (see section 6.1), making dynamic roads a non-accessible solution to the Zuidas space scarcity problem.

7.2 Recommendations

There are a few strategies that could be utilized in order to implement dynamic roads in a way that complies with the capabilities of the elderly community. These solutions take into account the limitations in the capabilities that an elderly population has, proposing amendments both to the dynamic roads plan, as well as to the Zuidas update plans. These recommendations hope to mitigate the problems of unpredictability that dynamic roads perpetuate, create opportunities for an elderly population to expand their capabilities, and maintain the accessibility of the current transportation network. In order to make dynamic roads work in an inclusive way, these considerations need to be taken into account to ensure that elderly users are not left stranded in a system they cannot participate in. Below will provide detail of the set of recommendations:

1. Flexible roads (predictable dynamic roads)
2. Information sessions
3. Stepped approach to car reduction

Flexible Roads

Through this research it is recommended to look at alternative options such as “flexible roads” without a true dynamic element. This alternative can be imagined as a derivative of dynamic roads, but the roads could change based on predicted demand at a set schedule, rather than based on demand in the moment. This would allow for some predictability to the schedule that could be learned by all community members, including elderly users. This idea builds on the concept of dynamic roads, but improves upon it by making it more universally accessible.

The predictability element would also solve the problem of dispersing information. Lacking the dynamic element, information could be given in a physical format that is more familiar to elderly populations, such as a pamphlet, or posted schedule at affected locations, similar to a posted bus schedule. This schedule could be published once, and then remain accurate, unlike with dynamic roads, which have to be constantly updated, prompting the use of smart devices as a tool for accessing information. By eliminating the dynamic variable, less capabilities are required to understand and use the road system. “Flexible roads” could still achieve the goals of dynamic roads, namely, allowing for a mix of uses for the same space based on (predicted) demand, while maintaining efficient throughput of users. Therefore, it is not necessary for the streets to be truly dynamic in order to have a positive effect on land use optimization. Instead, flexible roads with a set schedule would be an equitable alternative to the dynamic roads idea.

By switching to a predictable, flexible road scheme, the burden of usability is shifted off the users and on to the municipality or the public transport service provider. This means that instead of the users having to adapt to a new scheme and learn the corresponding technologies (smart devices to check the route), the municipality would be tasked with developing a schedule of road configurations that reflect the predicted user demand for the spaces.

Information Sessions

If it is determined that a truly dynamic street is necessary to optimize street space, then I would recommend using a strategy mentioned in the Toekomstvisie Social Vervoe (Gemeente Amsterdam, 2021), namely, involving established elderly organizations in information sessions organized by the transport region. These sessions could include technological literacy courses so that elderly people can gain the capabilities required to interact with the dynamic roads systems. By utilizing members of the community in the facilitation efforts, there is a greater depth of understanding of the limitations that the learners face. There is the added advantage of using familiar people and spaces to convey a sense of comfort while learning an unfamiliar technology (Alizadeh Asfestani et al., 2023). As Afestani et at. (2023) note, this strategy can help to ease tensions around new and daunting tasks, where using an outside teacher could facilitate a sense of mistrust and hesitancy to learn.

As suggested by Finkelstein et al., 2023, information sessions should begin by educating participants about the various opportunities associated with learning new technology. One of the main barriers to use is a lack of motivation, stemming from a lack of understanding about the potential usefulness of technology (Finkelstein et al., 2023). Once a motivation to learn has been established, it is easier to facilitate the lessons, so this first step is vital. As not all elderly users come from the same background of technological

understanding, lessons must be conducted on a case-by-case basis in order to have maximum impact. Similar to the way this study investigated the capabilities, an understanding of the way individuals perceive and use technology would also be beneficial for success in these sessions. I would recommend that these sessions incorporate a questionnaire to understand the capabilities and perceptions surrounding technology so to effectively tailor the lessons to these learned factors.

Stepped Approach to Reducing Car Usage to Ensure Inclusivity

Even though one of the goals for the Zuidas area update is to reduce the use of cars, the results of the survey indicate that this mode continues to be very popular among elderly people. Since this population is still very car dependent, it is important to take this pattern into account when designing a new road system to maintain their accessibility. At the same time, as dynamic roads aim to implement very new patterns of movement to the road network, it is important to bear in mind that elderly users are not as adaptable as a younger population. In order to maintain the road safety of this population, "new designs must match existing principles so that the elderly can use their experience and existing automatisms" (SWOV, 2015). Dynamic roads should not completely disregard established norms of road use. This can be accomplished while still keeping with Amsterdam's goal that ensuring social transport options should not hinder the ambitions for sustainability and technological innovation (Gemeente Amsterdam, 2021). A stepped approach can be used for the implementation of more radical changes. This means making incremental changes to the roads, and allowing for adaptation before implementation of the next step. For example, the addition of a dynamic bus lane, before more changes such as a dynamic cycle lane or replacing car parking spots with restaurant space.

7.3 Discussion

Applicability to Future Studies

As cities continue to increase in population, space becomes ever scarcer. This means that municipalities will have to get more creative with the ways they design roads and allocate space for mobility. Dynamic road space allocation is still quite a new topic and there are no real examples of it implemented anywhere in the world. However, it presents a new way of imagining our roads and allows for a more efficient use of space. For this reason, it will become an ever more relevant topic in years to come. As it gets implemented in urban spaces, it is vital that it not become another tool that perpetuates inequality, but rather becomes a resource to generate more opportunities for those who need it the most. In this study, utilizing social activities as an indicator of equitable wellbeing was touched on. This indicator can be further expanded upon to monitor the levels of wellbeing of different types of vulnerable communities.

The focus of this project on wellbeing and equity brings a socio-cultural lens to a larger program that is looking at reducing car usage in identified areas (XCARCITY, 2024). The dynamic roads element of this project is focused mainly on hard modelling for potential allocations. It is important that modeling solutions are balanced with socio-economic aspects to ensure the correct solution is created. This study on the travel and social behavior of the elderly population can also serve as a baseline to perform an ex-post evaluation of potential dynamic road projects in the future.

Finally, the conceptual framework and methodology applied in this study can serve as an example for ex ante studies on the implications of infrastructure updates on vulnerable populations. By first understanding the capabilities of a population, the effects of changes can better be understood, and negative consequences mitigated.

Limitations

Although this thesis made an attempt at discovering a multitude of factors that influence the mobility justice for a population, it is in no way comprehensive. There are risks that it could be used this way, but the study of equity is constantly evolving, and this will be a first step towards taking the considerations of justice into account as innovative road designs unfold.

The methodology was constrained by several factors such as technology use, language barrier, time for the project, and time for respondents. Since the survey was administered to an elderly population, many of whom may not be technologically literate, use of digital surveys was limited. Instead, the survey was administered in person, so to have a balanced response rate regardless of technological prowess. This is not the most efficient way of administering a survey to a large population, but it is the most equitable way to reach technologically challenged individuals.

Not speaking the native language of the target population poses another limitation. I was able to administer about 75% of the surveys in Dutch with the help of a few Dutch colleagues, but for the remaining 25% of surveys, I was unable to capture the data from many potential respondents because of the language barrier, this puts a slight bias in the results in favor of those who speak English. There is further limitation in recording survey results through colleagues, because I was not able to interpret their responses in the same way I was able to in English. When responding to questions, respondents often elaborate, allowing the administrator to form a more complete narrative. Although I was able to confer with my colleagues, I feel that some information was lost. Additionally, to maintain the interest of and keep the burden low for respondents, I kept the survey short and simple, leaving out various questions that might have also provided some insight for the project.

The time schedule of this master's thesis proved to be the most constraining factor. In order to be able to complete the project on time the survey time was constrained and limited the ability to gather a larger sample size and gain a higher confidence interval.

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Appendix A: Survey

Mobility Choices Survey

Thank you considering participation in this study. Your input is very helpful to us and by participating, you have the opportunity to help improve the mobility options available to you and your neighbors. This survey is designed to gain an understanding of the travel behaviors of the residents closest to the Zuidas station. It is important to have this information so that any new design updates make access to the city better for all.

This survey includes questions both on technologial ability as well as travel preferences. All data collected will remain anonymous (we will not record your name, address, or any contact details). Should you choose to participate in the study, your opinions will be taken into consideration in the design of the upcoming project.

I consent to the data I provide in this form being used in the ways described above

By selecting OK you agree that: you participate on a voluntary basis, understand the purpose of the study, and the ways in which your data will be used; consent to have your provided answers be processed for the purpose of this study, give permission for the data to be stored and accessed by authorized members, and permission to reuse your data for future research in travel related projects.

- ◯ OK

Thank you for your time

How do you identify?

- ◯ Male
- ◯ Female
- ◯ Non-binary
- ◯ I would like to describe my gender identity myself

Gender identity

What age group do you belong to?

- ◯ 18-25
- ◯ 26-50
- ◯ 51-65
- ◯ 66-75
- ◯ 75-80
- ◯ 80+

Are you retired?

- ◯ Yes
- ◯ No

The next few questions will ask about your technological capabilities

---

Do you own a smartphone or other smart device?

- ◯ Yes
- ◯ No

Can you use a smart device?

- ◯ Yes
- ◯ No

What do you use your smart device for? (select all that apply)

- ☐ Communication (calling, texting, email)
- ☐ Navigation (mapping)
- ☐ Route Scheduling (NS app, 9292, google maps)
- ☐ Other

Please describe

_____

The next several questions will ask about your travel preferences and what influences your choice

_____

How often do you travel from the Amsterdam Zuid station? (Either by bus, train, tram, metro, or OV-bike)

- ◯ Almost never
- ◯ Rarely (1-2 times a month)
- ◯ Sometimes (1-3 times a week)
- ◯ Frequently (4-5 times a week)
- ◯ Almost every day

How do you travel for most trips? Via...

Select up to three options

- ☐ Car (driving)
- ☐ Car (passenger)
- ☐ Bicycle
- ☐ OV-Fiets (or other shared bicycle)
- ☐ Public Transportation (train, bus, tram)
- ☐ E-bike/E-scooter (personal)
- ☐ E-bike/E-scooter (shared)
- ☐ Car share (ex. Greenwheels)
- ☐ Walk
- ☐ Other

Please describe

_____

What is your main motivation for your travel choice?

Select up to five answers

- [ ] It is the fastest
- [ ] It is the cheapest
- [ ] It is the safest
- [ ] It is the most fun
- [ ] It is the most convenient
- [ ] It is the most comfortable
- [ ] It is closest to where I live
- [ ] It is the only option at the times I travel
- [ ] It is the only option to reach a specific destination
- [ ] It is the only option I am capable of using
- [ ] It is good for exercise
- [ ] It is good for the environment
- [ ] Other

If this way of traveling was suddenly unavailable, would you still be able to reach your desired destinations?

Such as family, supermarket, recreation?

- ◯ I could reach all destinations
- ◯ I could reach most destinations
- ◯ I could reach some destinations
- ◯ I could reach very few destinations
- ◯ I could no longer reach any destinations

How likely are you to change your travel pattern based on the following factors? (changing travel method) *From unlikely (1) to very likely (5)*	1	2	3	4	5
Traffic congestion	◯	◯	◯	◯	◯
Monetary cost	◯	◯	◯	◯	◯
Travel time	◯	◯	◯	◯	◯
Comfort (availability of seating, space)	◯	◯	◯	◯	◯
Traffic safety	◯	◯	◯	◯	◯
Environmental concern	◯	◯	◯	◯	◯
Physical accessibility of built environment	◯	◯	◯	◯	◯

Do you check your route for the above conditions before you leave via a smart device?

- Always
- Sometimes
- Never
- I check the route, but not with a smart device

Please elaborate

_____

Do you usually travel around the same time of day?

- Yes, I have a set schedule
- No, my schedule is flexible
- It depends

If yes to the previous question, what time of day do you normally travel?

- Peak hours morning (6:30- 9:00, weekdays)
- Peak hours afternoon (16:00-18:30, weekdays)
- Off-peak hours

The last few questions will ask about your quality of life and overall wellbeing in terms of mobility

_____

On average, how many times per week do you engage in social activities? (ex. meeting up with friends, family)

- Less than 1
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 7+

How do you use to get to social engagements? Via...

- [ ] Car
- [ ] Bicycle
- [ ] OV- Fiets (or other shared bike)
- [ ] Public Transportation (Train, bus, tram)
- [ ] E-bike/E-scooter (personal)
- [ ] E-bike/E-scooter (shared)
- [ ] Car share (ex. Greenwheels)
- [ ] Walk
- [ ] Other

Please describe

_____

Rate your agreement with the following statements *From strongly disagree (1) to strongly agree (5)*	1	2	3	4	5
I am likely to use public transportation	◯	◯	◯	◯	◯
I feel safe getting to and from public transportation	◯	◯	◯	◯	◯
My happiness is affected by my ability to travel in the city	◯	◯	◯	◯	◯
I am satisfied with the current mobility options available to me	◯	◯	◯	◯	◯
I am confident in my ability to use smart technology (smartphone, tablet)	◯	◯	◯	◯	◯
I have a full and satisfying social life	◯	◯	◯	◯	◯
I can travel in a way that is suited to my physical condition and abilities	◯	◯	◯	◯	◯
I can use my preferred way of travelling to reach destinations in the city	◯	◯	◯	◯	◯

Are there places you would like to be able to go in the city but feel you cannot get to?

- ◯ Yes
- ◯ No
- ◯ I do not know

Which activities do you feel unable to reach?

- [ ] Grocery
- [ ] Green space (park)
- [ ] Social activities (family/friends homes)
- [ ] Social activities (bars/restaurants)
- [ ] Medical facilities
- [ ] Other

Please describe

_____

Please describe what limitations you feel restrict your movement

- [ ] There is no safe route to where I want to go
- [ ] Physical impairments
- [ ] Trouble navigating
- [ ] Trouble using public transportation
- [ ] Public transportation does not service the places I want to go
- [ ] Unable to drive
- [ ] Unable to park
- [ ] Unable to cycle
- [ ] It takes too long to get to where I want to go